Application of the Sea-Level Affecting Marshes Model (SLAMM 5.0) to Bon Secour National Wildlife Refuge

Prepared For: Dr. Brian Czech, Conservation Biologist

U. S. Fish and Wildlife Service
National Wildlife Refuge System
Division of Natural Resources and Conservation Planning
Conservation Biology Program
4401 N. Fairfax Drive - MS 670
Arlington, VA 22203

July 15, 2009

Jonathan S. Clough & Evan C. Larson, Warren Pinnacle Consulting, Inc.
PO Box 253, Warren VT, 05674
(802)-496-3476

Application of the Sea-Level Affecting Marshes Model (SLAMM 5.0) to Bon Secour National Wildlife Refuge

Introduction

Tidal marshes are among the most susceptible ecosystems to climate change, especially accelerated sea level rise (SLR). The International Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) suggested that global sea level will increase by approximately 30 cm to 100 cm by 2100 (IPCC 2001). Rahmstorf (2007) suggests that this range may be too conservative and that the feasible range by 2100 could be 50 to 140 cm. Pfeffer et al. (2008) suggests that 200 cm by 2100 is at the upper end of plausible scenarios due to physical limitations on glaciological conditions. Rising sea level may result in tidal marsh submergence (Moorhead and Brinson 1995) and habitat migration as salt marshes transgress landward and replace tidal freshwater and irregularly flooded marsh (Park et al. 1991).

In an effort to address the potential effects of sea level rise on United States national wildlife refuges, the U. S. Fish and Wildlife Service contracted the application of the SLAMM model for most Region 4 refuges. This analysis is designed to assist in the production of comprehensive conservation plans (CCPs) for each refuge along with other long-term management plans.

Model Summary

Changes in tidal marsh area and habitat type in response to sea-level rise were modeled using the Sea Level Affecting Marshes Model (SLAMM 5.0) that accounts for the dominant processes involved in wetland conversion and shoreline modifications during long-term sea level rise (Park et al. 1989; www.warrenpinnacle.com/prof/SLAMM).

Successive versions of the model have been used to estimate the impacts of sea level rise on the coasts of the U.S. (Titus et al., 1991; Lee, J.K., R.A. Park, and P.W. Mausel. 1992; Park, R.A., J.K. Lee, and D. Canning 1993; Galbraith, H., R. Jones, R.A. Park, J.S. Clough, S. Herrod-Julius, B. Harrington, and G. Page. 2002; National Wildlife Federation et al., 2006; Glick, Clough, et al. 2007; Craft et al., 2009.

Within SLAMM, there are five primary processes that affect wetland fate under different scenarios of sea-level rise:

- **Inundation:** The rise of water levels and the salt boundary are tracked by reducing elevations of each cell as sea levels rise, thus keeping mean tide level (MTL) constant at zero. The effects on each cell are calculated based on the minimum elevation and slope of that cell.
- **Erosion:** Erosion is triggered based on a threshold of maximum fetch and the proximity of the marsh to estuarine water or open ocean. When these conditions are met, horizontal erosion occurs at a rate based on site-specific parameters.
- **Overwash:** Barrier islands of under 500 meters width are assumed to undergo overwash during each 25-year time-step due to storms. Beach migration and transport of sediments are calculated.
- **Saturation:** Coastal swamps and fresh marshes can migrate onto adjacent uplands as a response of the fresh water table to rising sea level close to the coast.

- **Accretion:** Sea level rise is offset by sedimentation and vertical accretion using average or site-specific values for each wetland category. Accretion rates may be spatially variable within a given model domain.

SLAMM Version 5.0 is the latest version of the SLAMM Model, developed in 2006/2007 and based on SLAMM 4.0. SLAMM 5.0 provides the following refinements:

- The capability to simulate fixed levels of sea-level rise by 2100 in case IPCC estimates of sea-level rise prove to be too conservative;
- Additional model categories such as "Inland Shore," "Irregularly Flooded (Brackish) Marsh," and "Tidal Swamp."
- *Optional.* In a defined estuary, salt marsh, brackish marsh, and tidal fresh marsh can migrate based on changes in salinity, using a simple though geographically-realistic salt wedge model. This optional model was not used when creating results for Bon Secour.

Model results presented in this report were produced using SLAMM version 5.0.1 which was released in early 2008 based on only minor refinements to the original SLAMM 5.0 model. Specifically, the accretion rates for swamps were modified based on additional literature review. For a thorough accounting of SLAMM model processes and the underlying assumptions and equations, please see the SLAMM 5.0.1 technical documentation (Clough and Park, 2008). This document is available at http://warrenpinnacle.com/prof/SLAMM

Sea-Level Rise Scenarios

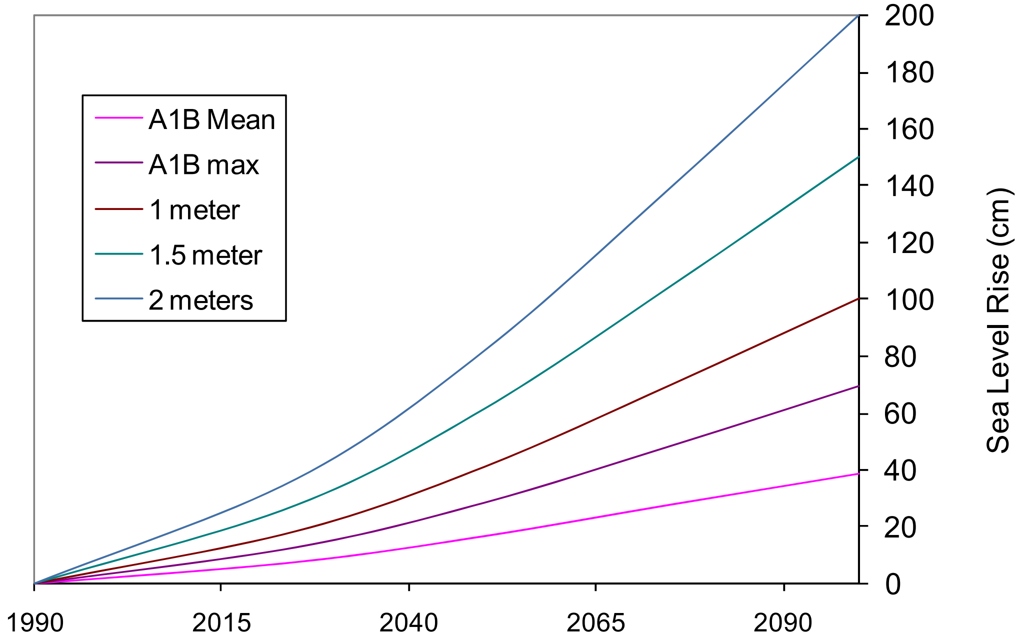
The primary set of eustatic (global) sea level rise scenarios used within SLAMM was derived from the work of the Intergovernmental Panel on Climate Change (IPCC 2001). SLAMM 5 was run using the following IPCC and fixed-rate scenarios:

Scenario	Eustatic SLR by 2025 (cm)	Eustatic SLR by 2050 (cm)	Eustatic SLR by 2075 (cm)	Eustatic SLR by 2100 (cm)
A1B Mean	8	17	28	39
A1B Max	14	30	49	69
1 meter	13	28	48	100
1.5 meter	18	41	70	150

Recent literature (Chen et al., 2006, Monaghan et al., 2006) indicates that the eustatic rise in sea levels is progressing more rapidly than was previously assumed, perhaps due to the dynamic changes in ice flow omitted within the IPCC report's calculations. A recent paper in the journal *Science* (Rahmstorf, 2007) suggests that, taking into account possible model error, a feasible range by 2100 might be 50 to 140 cm. A recent US intergovernmental report states "Although no ice-sheet model is currently capable of capturing the glacier speedups in Antarctica or Greenland that have been observed over the last decade, including these processes in models will very likely show that IPCC AR4 projected sea level rises for the end of the 21st century are too low." (US Climate Change Science Program, 2008)

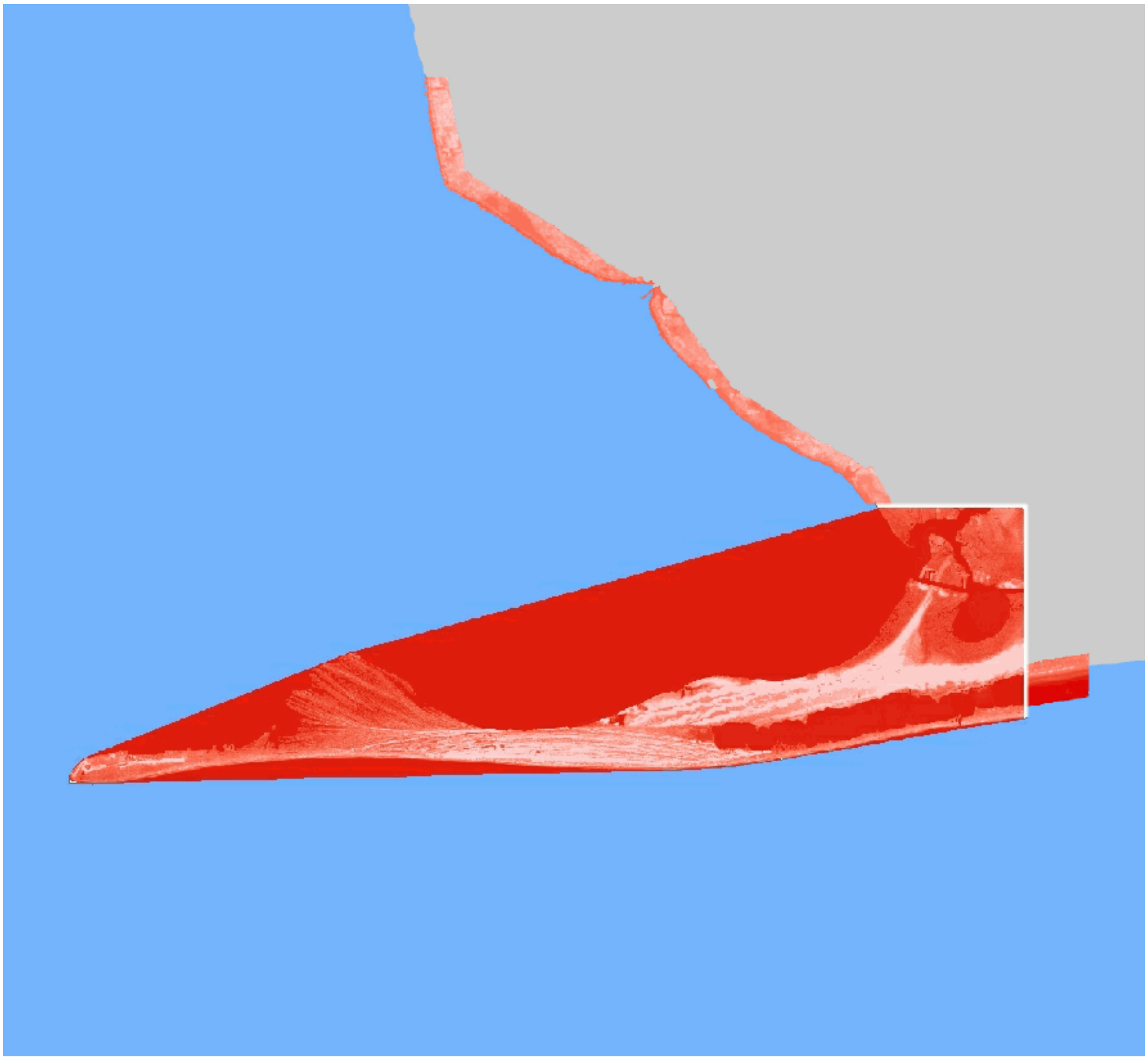
To allow for flexibility when interpreting the results, SLAMM was also run assuming 1 meter, 1½ meters, and 2 meters of eustatic sea-level rise by the year 2100. The A1B- maximum scenario was scaled up to produce these bounding scenarios (Figure 1).

Figure 1: Summary of SLR Scenarios Utilized



Methods and Data Sources

LiDAR data are available for the Bon Secour National Wildlife Refuge as shown in the map below. For regions in which LiDAR data are not available (primarily outside of refuge boundaries), the National Elevation Dataset was utilized. This dataset was derived from USGS maps with a 1976 source date and a contour elevation of two meters.



Extent of NOAA LiDAR Data Utilized Preferentially for this Analysis (red portions)

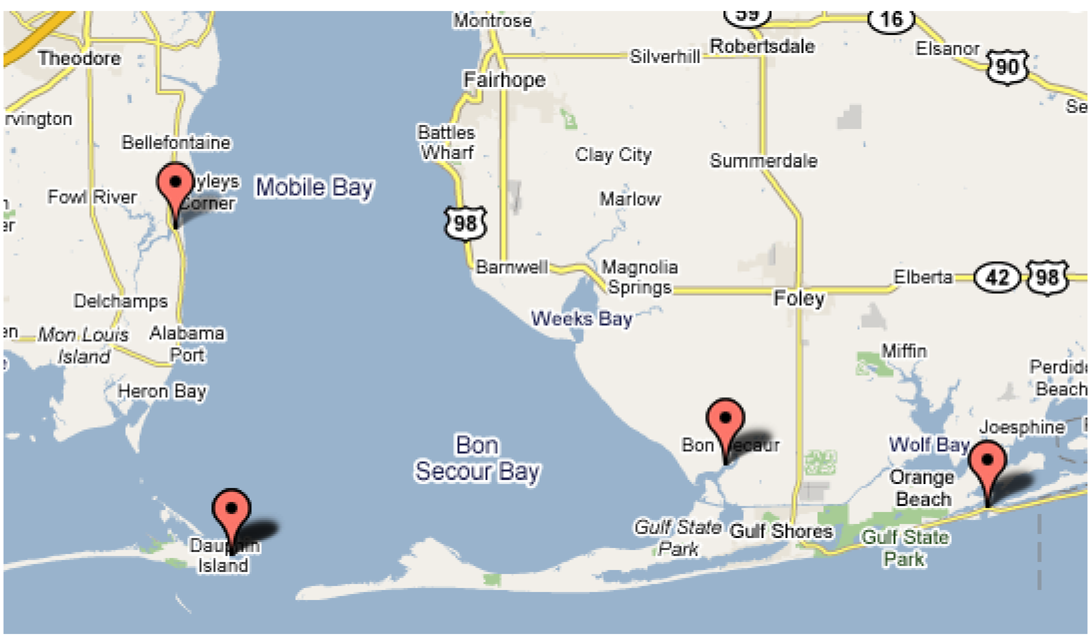
The National Wetlands Inventory for Bon Secour is based on a photo date of 1988. This survey, when converted to 30 meter cells, suggests that the approximately twelve thousand acre refuge (approved acquisition boundary) is composed primarily of swamp, dry land, brackish marsh, and inland fresh marsh (see table below).

Swamp	45.2%
Dry Land	19.6%
Brackish Marsh	17.0%
Inland Fresh Marsh	9.9%
Estuarine Open Water	2.7%
Tidal Fresh Marsh	1.5%
Saltmarsh	1.2%
Tidal Swamp	0.7%
Ocean Beach	0.5%
Open Ocean	0.4%
Trans. Salt Marsh	0.4%
Inland Open Water	0.3%
Estuarine Beach	0.3%
Cypress Swamp	0.2%

Land Cover Classes Derived from NWI Inventory

The historic trend for Sea Level Rise was calculated at 2.93 mm/year based on long term trends measured at Dauphin Island, Alabama (NOAA station 8735180, dating back to 1966).

The oceanic tide range was estimated at 0.470 meters using the closest NOAA station, Bon Secour, AL (8735181). Data from Dauphin Island (8728229) and Fowl River (8735523) were within 0.1 meters of this level.



NOAA Stations used to gather tide data for Bon Secour

No site-specific or Alabama-specific studies of vertical accretion of wetlands were found to support this analysis. Salt marsh accretion rates were therefore set to the same values as used in St. Mark's NWR Florida or 4.0 mm/year. This is in the middle of the range of values measured within Florida but not as high as the accretion rates measured in Louisiana.

The MTL to NAVD correction was derived using the NOAA VDATUM product. Multiple geographic points were input into VDATUM to produce several corrections in the study area. The resulting correction value is an average of these values which did not differ appreciably.

Modeled U.S. Fish and Wildlife Service refuge boundaries are based on Approved Acquisition Boundaries as received from Kimberly Eldridge, lead cartographer with U.S. Fish and Wildlife Service, and are current as of June, 2008.

The cell-size used for this analysis was 30 meter by 30 meter cells. However, the SLAMM model does track partial conversion of cells based on elevation and slope.

SLAMM INPUT PARAMETERS FOR Bon Secour

Site	**Bon Secour**	**Bon Secour LiDAR**
NED Source Date (yyyy)	1976	2005
NWI_photo_date (yyyy)	1988	1988
Direction_OffShore (N|S|E|W)	W	W
Historic_trend (mm/yr)	2.93	2.93
NAVD88_correction (MTL-NAVD88 in meters)	0.114	0.114
Water Depth (m below MLW- N/A)	2	2
TideRangeOcean (meters: MHHW-MLLW)	0.470	0.470
TideRangeInland (meters)	0.470	0.470
Mean High Water Spring (m above MTL)	0.313	0.313
MHSW Inland (m above MTL)	0.313	0.313
Marsh Erosion (horz meters/year)	1.8	1.8
Swamp Erosion (horz meters/year)	1	1
TFlat Erosion (horz meters/year) [from 0.5]	0.5	0.5
Salt marsh vertical accretion (mm/yr) Final	4.0	4.0
Brackish March vert. accretion (mm/yr) Final	4.7	4.7
Tidal Fresh vertical accretion (mm/yr) Final	5.9	5.9
Beach/T.Flat Sedimentation Rate (mm/yr)	0.5	0.5
Frequency of Large Storms (yr/washover)	25	25
Use Elevation Preprocessor for Wetlands ,	TRUE	FALSE

Results

SLR by 2100 (m)	0.39	0.69	1	1.5
Swamp	10%	20%	33%	58%
Dry Land	11%	15%	22%	35%
Brackish Marsh	14%	27%	65%	94%
Inland Fresh Marsh	-1%	-1%	0%	6%
Tidal Fresh Marsh	1%	2%	9%	70%
Tidal Swamp	71%	87%	94%	98%
Ocean Beach	19%	8%	50%	38%
Cypress Swamp	0%	0%	0%	10%
Inland Shore	0%	0%	7%	86%

Predicted Loss Rates of Land Categories by 2100 Given Simulated Scenarios of Eustatic Sea Level Rise

Swamp lands are predicted to be somewhat resilient at this site. Even under a scenario of one meter of sea level rise by 2100, only 33% of swamp lands at this location are predicted to be lost. The one point five meter scenario is more severe, though, resulting in a loss of 58%. The reason for this resiliency appears to be a combination of initial elevation (most of this based on LiDAR data) and a lower historical rate of sea level rise than some other sites (Louisiana, for example). Dry land loss rates range from 11% (under 0.39 meters of SLR) to 35% (under 1.5 meters of SLR).

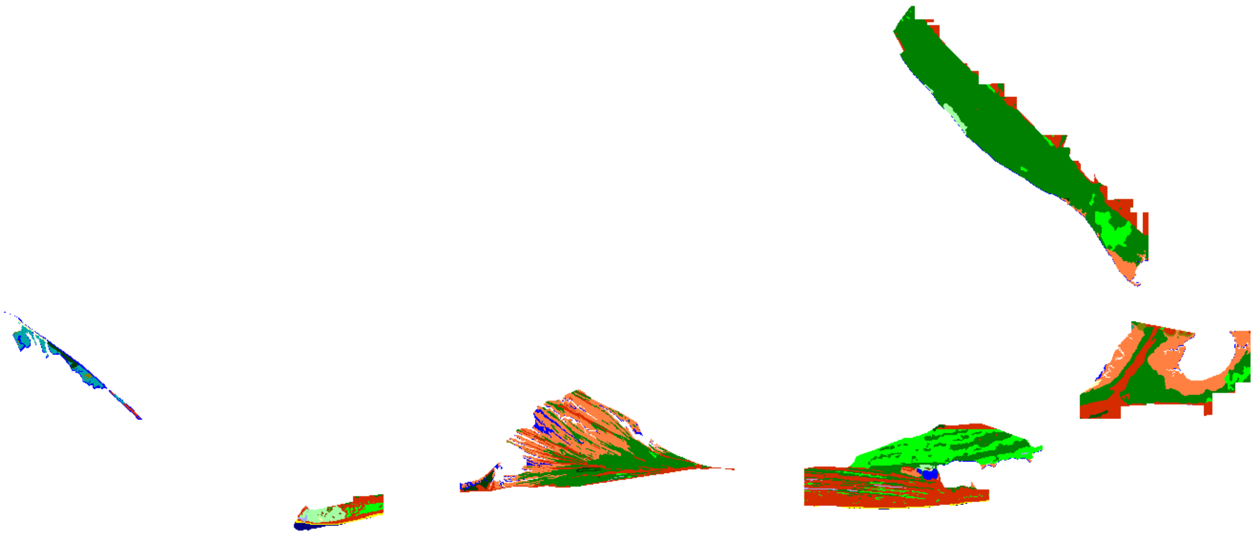
Brackish marsh at this site is predicted to be more vulnerable than swamps. Under the lowest scenario of sea level rise, the loss of brackish marsh is only predicted to be 14%. However, increasing the SLR scenario to 1 meter by 2100 increases the predicted loss to 65%. Once SLR exceeds accretion rates for this category it is predicted to be nearly completely lost.

Maps of SLAMM input and output to follow will use the following legend:

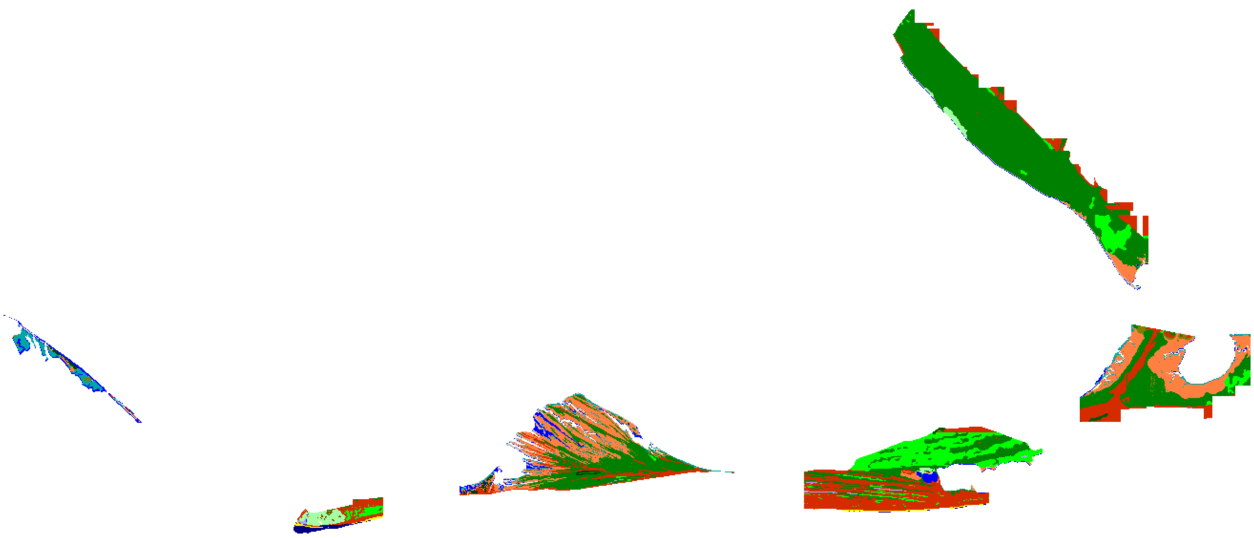
Bon Secour NWR
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

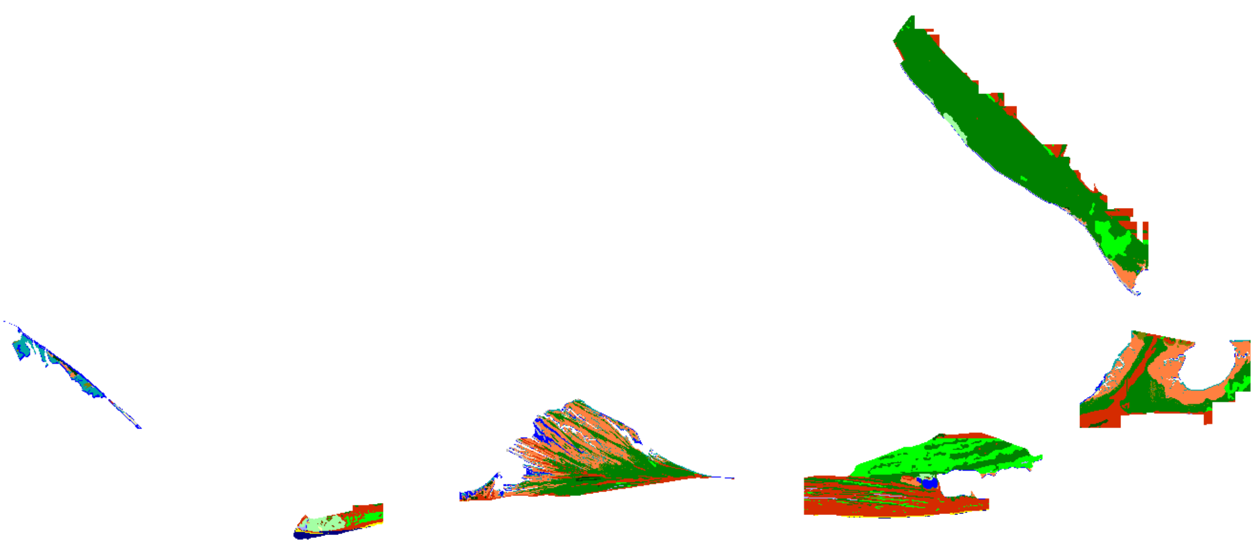
	Initial	2025	2050	2075	2100
Swamp	5510.0	5501.2	5436.5	5253.4	4981.0
Dry Land	2395.0	2236.2	2191.3	2169.9	2135.3
Brackish Marsh	2072.5	1804.8	1802.3	1810.4	1787.8
Inland Fresh Marsh	1212.3	1216.1	1219.4	1219.5	1219.6
Estuarine Open Water	333.6	357.7	430.1	513.4	583.3
Tidal Fresh Marsh	181.5	179.4	179.4	179.4	179.4
Saltmarsh	140.8	373.9	370.9	396.3	485.5
Tidal Swamp	87.2	59.5	47.5	35.3	25.2
Ocean Beach	65.8	56.5	54.5	53.2	53.1
Open Ocean	47.6	70.2	73.5	77.6	83.3
Trans. Salt Marsh	46.0	95.8	159.2	286.7	423.5
Inland Open Water	38.5	37.1	37.1	35.6	34.5
Estuarine Beach	32.9	25.6	30.7	35.9	35.8
Cypress Swamp	22.5	22.5	22.5	22.5	22.5
Inland Shore	11.3	11.3	11.3	11.3	11.3
Tidal Flat	1.6	151.1	132.8	98.6	137.9
Total (incl. water)	**12199.0**	**12199.0**	**12199.0**	**12199.0**	**12199.0**



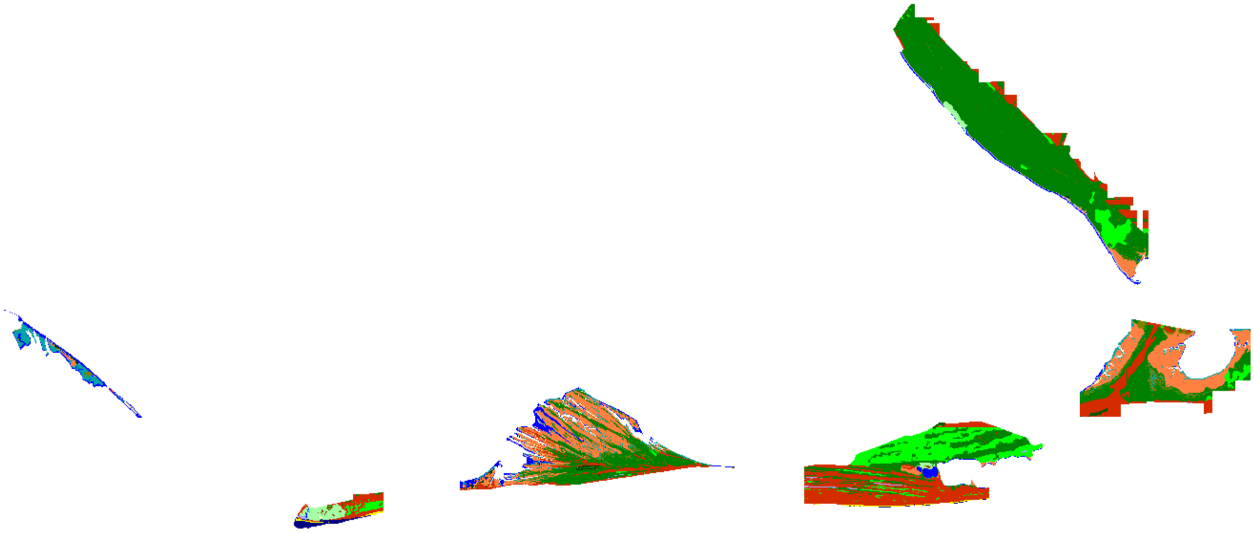
Bon Secour, Initial Condition



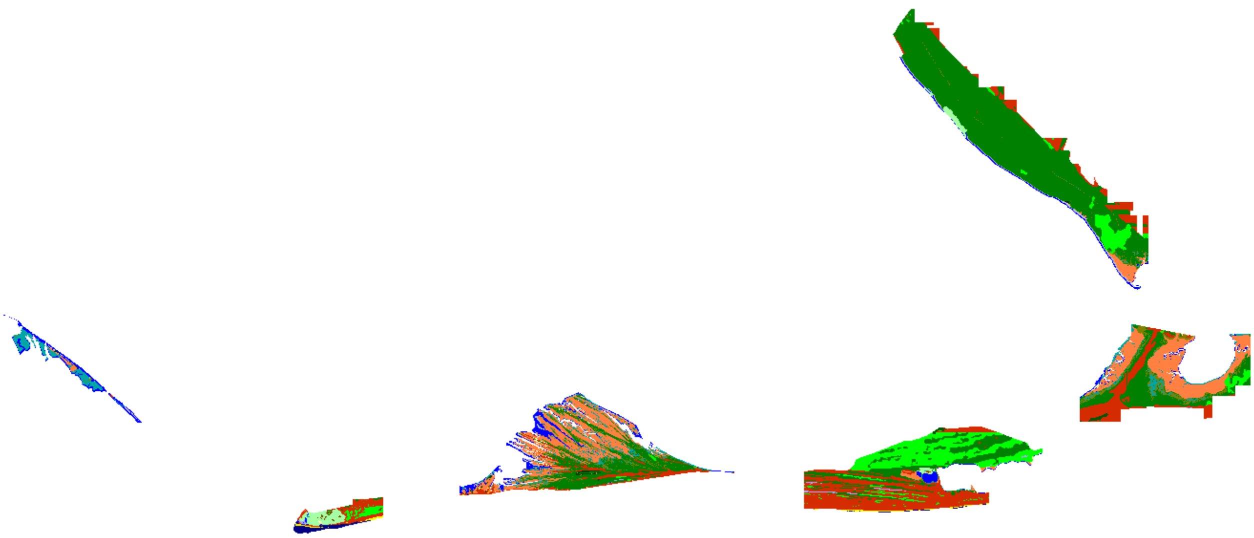
Bon Secour, 2025 Scenario A1B-Mean



Bon Secour, 2050 Scenario A1B-Mean



Bon Secour, 2075 Scenario A1B-Mean

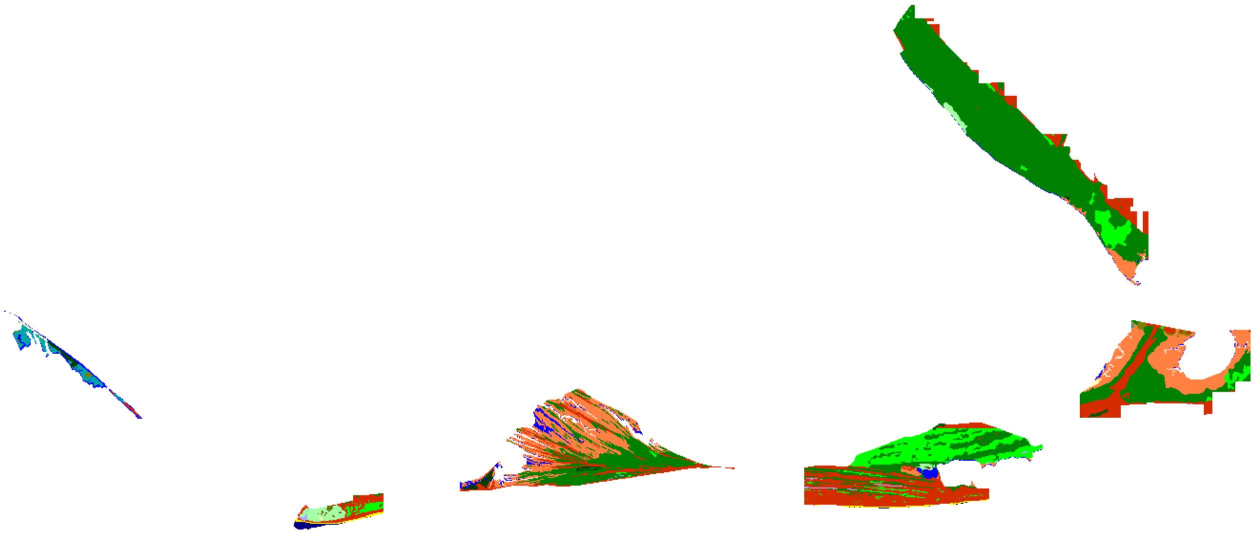


Bon Secour, 2100 Scenario A1B-Mean

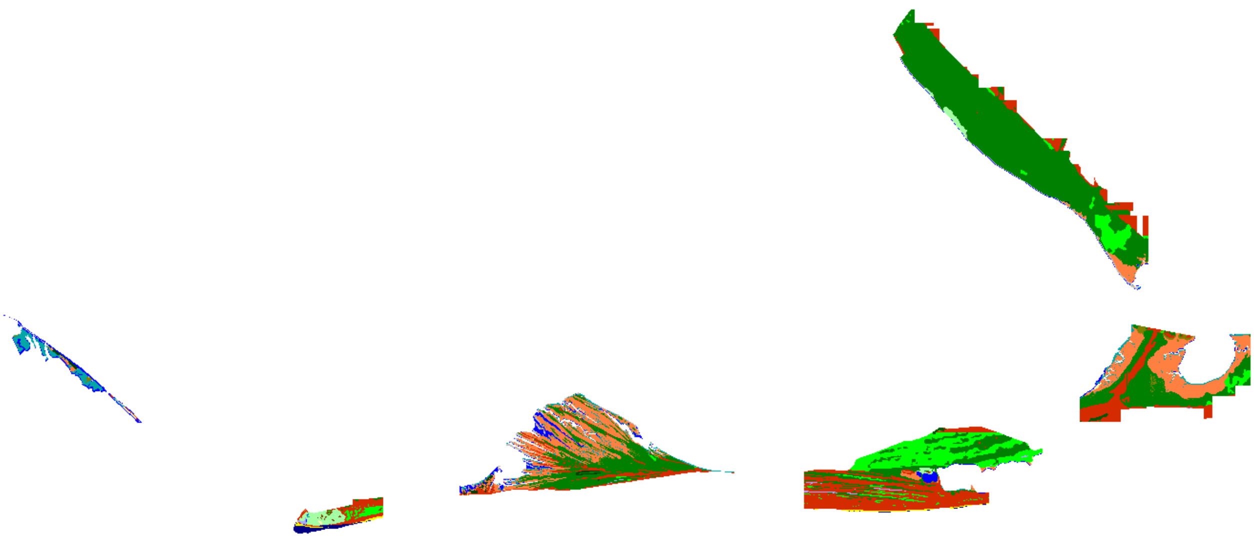
Bon Secour NWR
IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

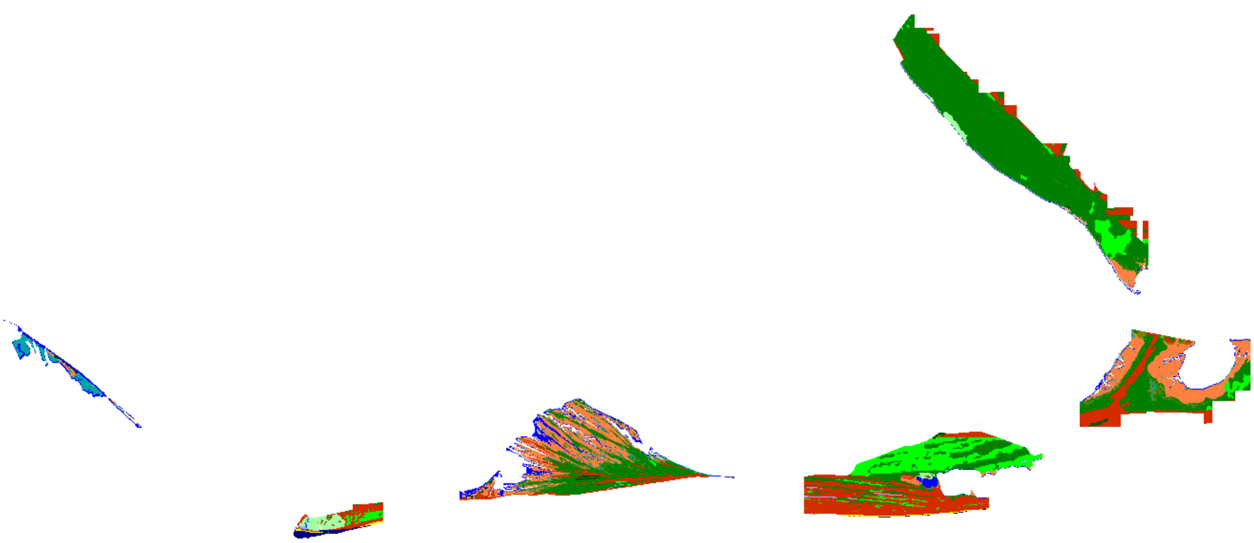
	Initial	2025	2050	2075	2100
Swamp	5510.0	5479.3	5305.4	4868.8	4426.8
Dry Land	2395.0	2225.8	2172.1	2114.4	2024.2
Brackish Marsh	2072.5	1804.9	1765.9	1680.5	1519.5
Inland Fresh Marsh	1212.3	1216.1	1219.4	1219.1	1218.6
Estuarine Open Water	333.6	386.9	527.4	719.8	919.8
Tidal Fresh Marsh	181.5	179.4	179.4	178.5	177.1
Saltmarsh	140.8	366.3	372.0	486.6	926.5
Tidal Swamp	87.2	53.3	36.5	20.9	11.3
Ocean Beach	65.8	55.3	53.2	52.1	60.3
Open Ocean	47.6	71.8	76.4	87.2	104.5
Trans. Salt Marsh	46.0	113.9	229.4	478.7	496.1
Inland Open Water	38.5	37.1	36.5	34.2	30.2
Estuarine Beach	32.9	29.4	36.8	38.2	42.6
Cypress Swamp	22.5	22.5	22.5	22.5	22.5
Inland Shore	11.3	11.3	11.3	11.3	11.3
Tidal Flat	1.6	145.4	154.7	186.0	207.6
Total (incl. water)	**12199.0**	**12199.0**	**12199.0**	**12199.0**	**12199.0**



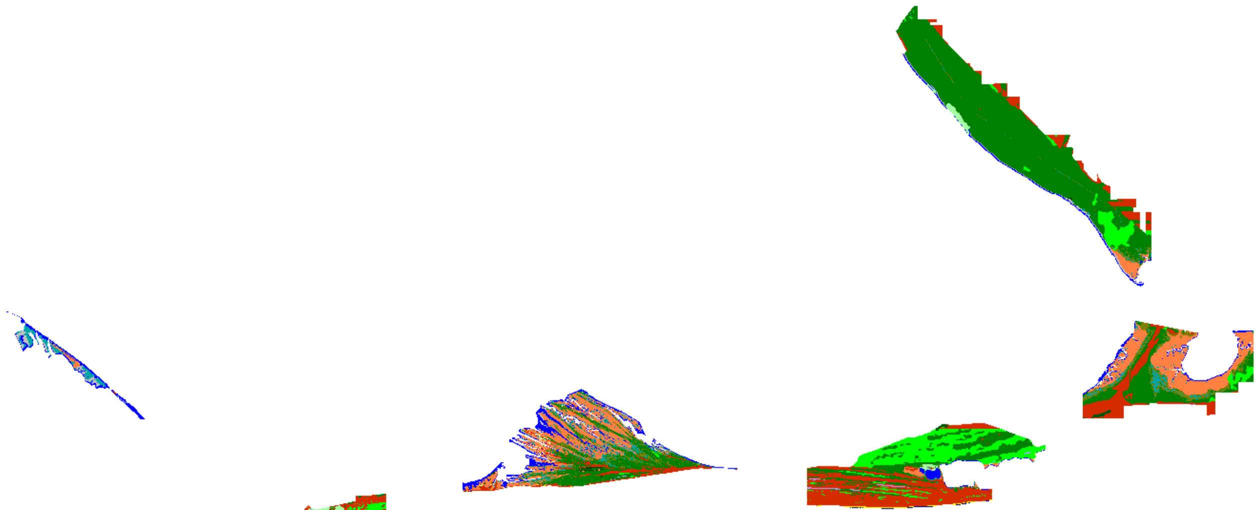
Bon Secour, Initial Condition



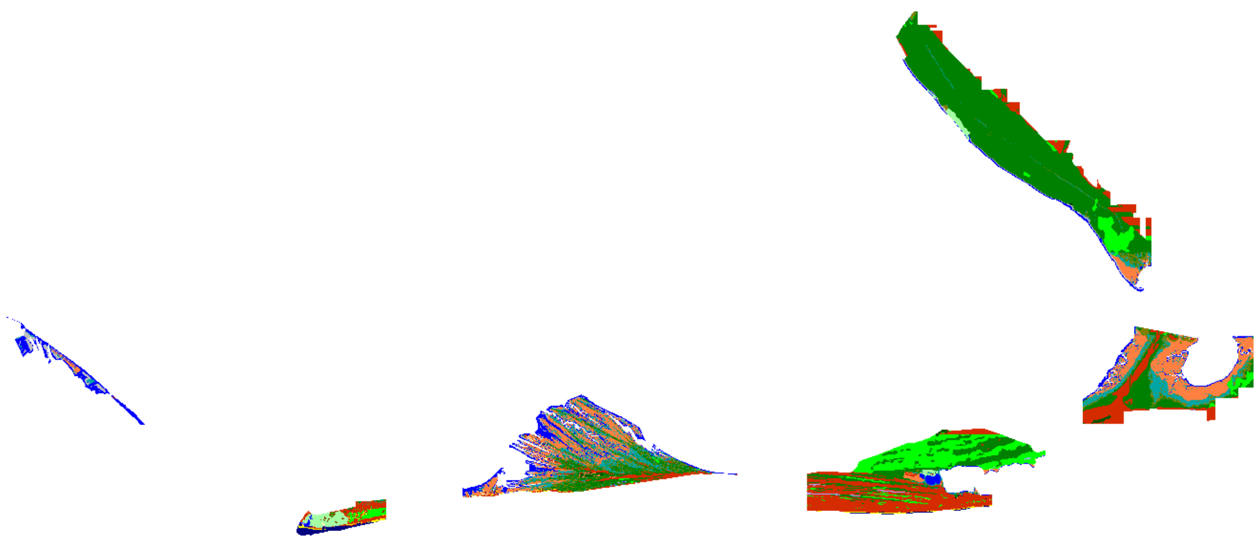
Bon Secour, 2025 Scenario A1B-Maximum



Bon Secour, 2050 Scenario A1B-Maximum



Bon Secour, 2075 Scenario A1B-Maximum

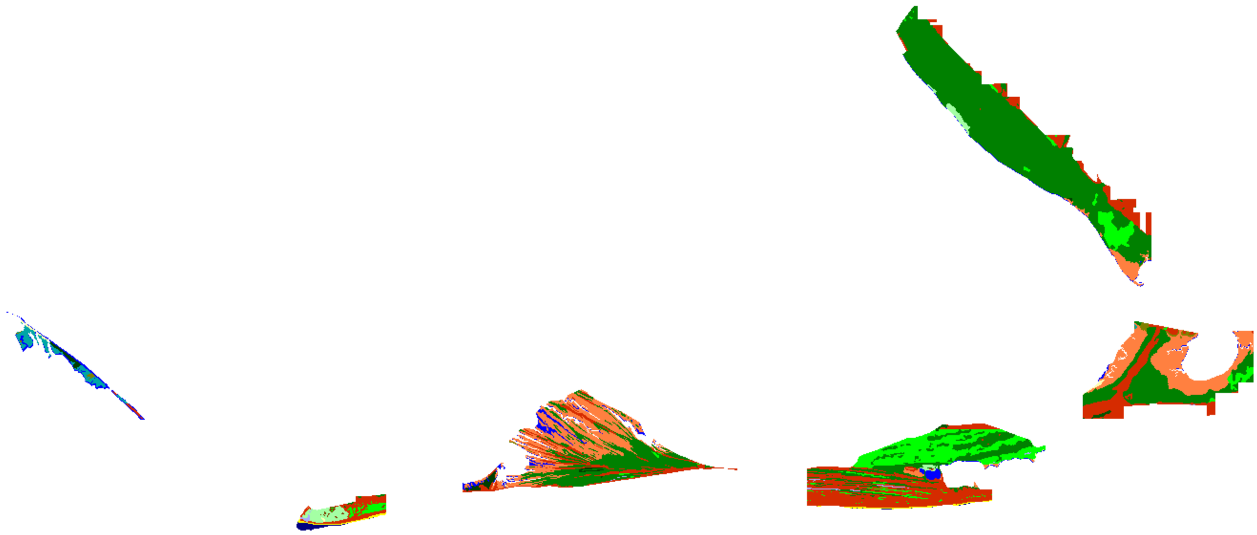


Bon Secour, 2100 Scenario A1B-Maximum

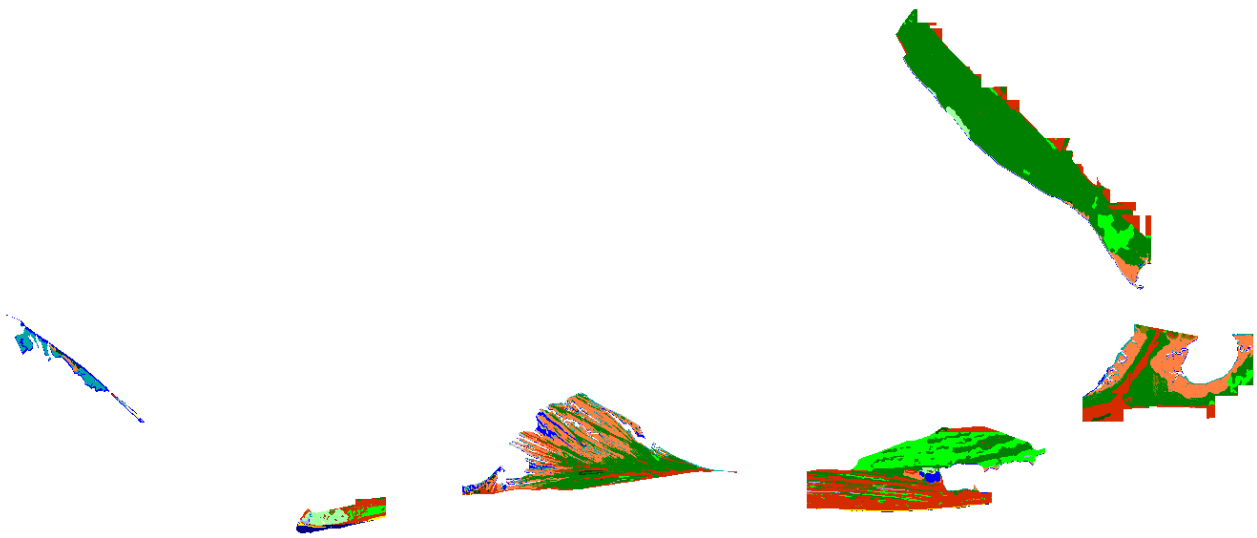
Bon Secour NWR
1 Meter Eustatic SLR by 2100

Results in Acres

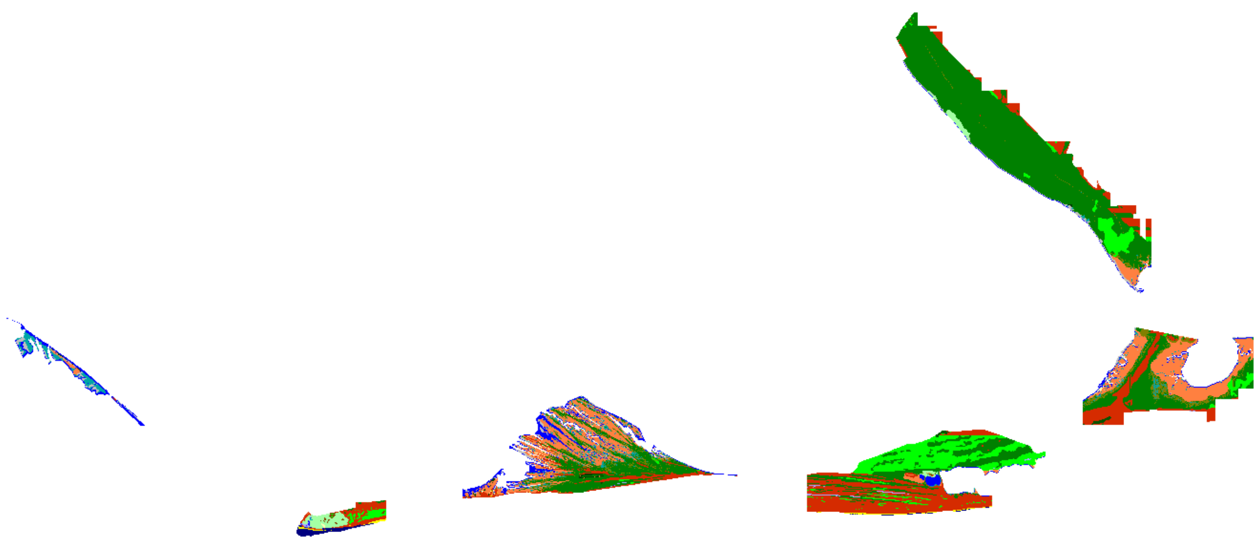
	Initial	2025	2050	2075	2100
Swamp	5510.0	5443.4	5086.0	4481.7	3669.2
Dry Land	2395.0	2215.0	2143.1	2038.9	1868.1
Brackish Marsh	2072.5	1780.7	1688.7	1366.8	719.5
Inland Fresh Marsh	1212.3	1216.1	1218.9	1216.3	1207.9
Estuarine Open Water	333.6	432.4	618.3	910.4	1380.7
Tidal Fresh Marsh	181.5	179.3	177.9	175.0	165.3
Saltmarsh	140.8	370.6	370.4	815.1	1448.3
Tidal Swamp	87.2	46.8	25.7	11.8	4.9
Ocean Beach	65.8	53.6	50.7	52.3	33.0
Open Ocean	47.6	73.9	82.2	104.6	178.7
Trans. Salt Marsh	46.0	141.6	415.2	665.7	914.4
Inland Open Water	38.5	37.1	34.9	30.5	28.9
Estuarine Beach	32.9	33.6	37.4	43.8	42.3
Cypress Swamp	22.5	22.5	22.5	22.5	22.5
Inland Shore	11.3	11.3	11.3	11.3	10.6
Tidal Flat	1.6	141.0	215.6	252.2	504.7
Total (incl. water)	**12199.0**	**12199.0**	**12199.0**	**12199.0**	**12199.0**



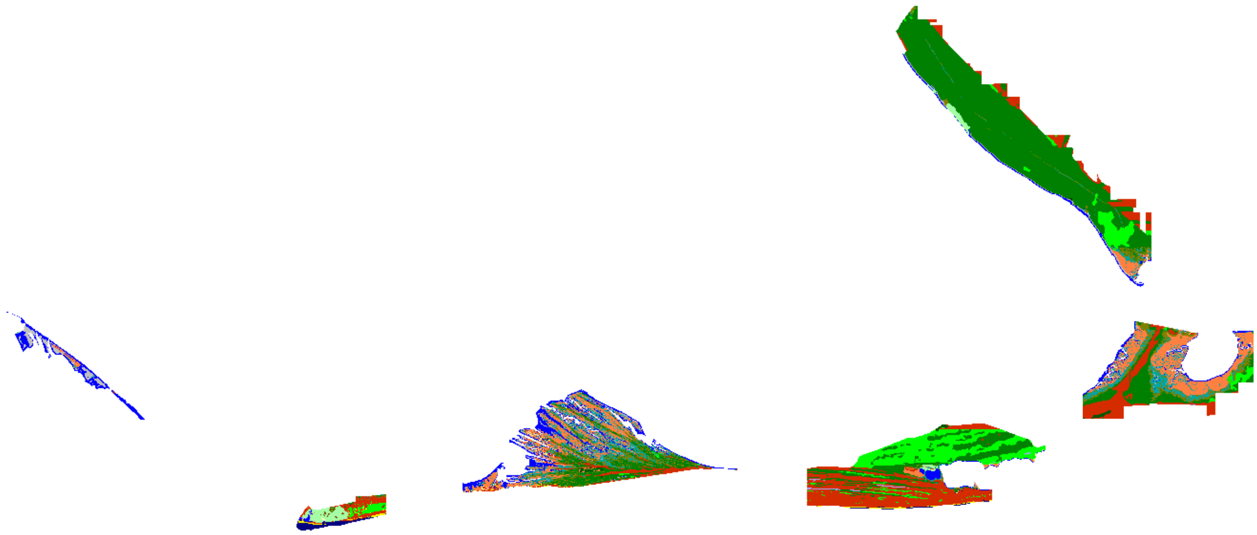
Bon Secour, Initial Condition



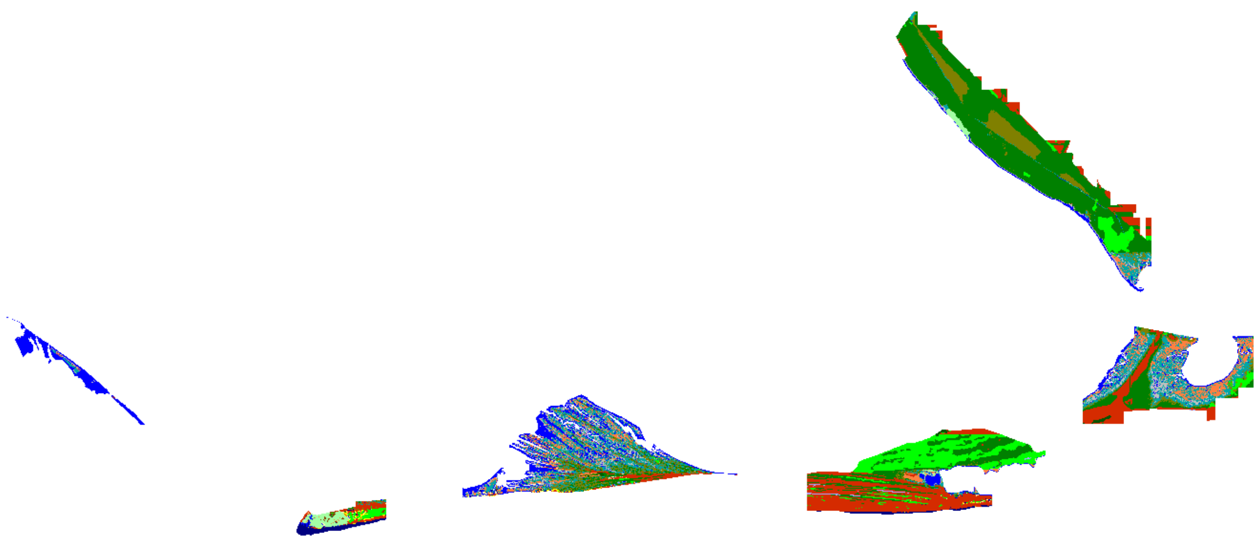
Bon Secour, 2025, 1 Meter Eustatic by 2100



Bon Secour, 2050, 1 Meter Eustatic by 2100



Bon Secour, 2075, 1 Meter Eustatic by 2100

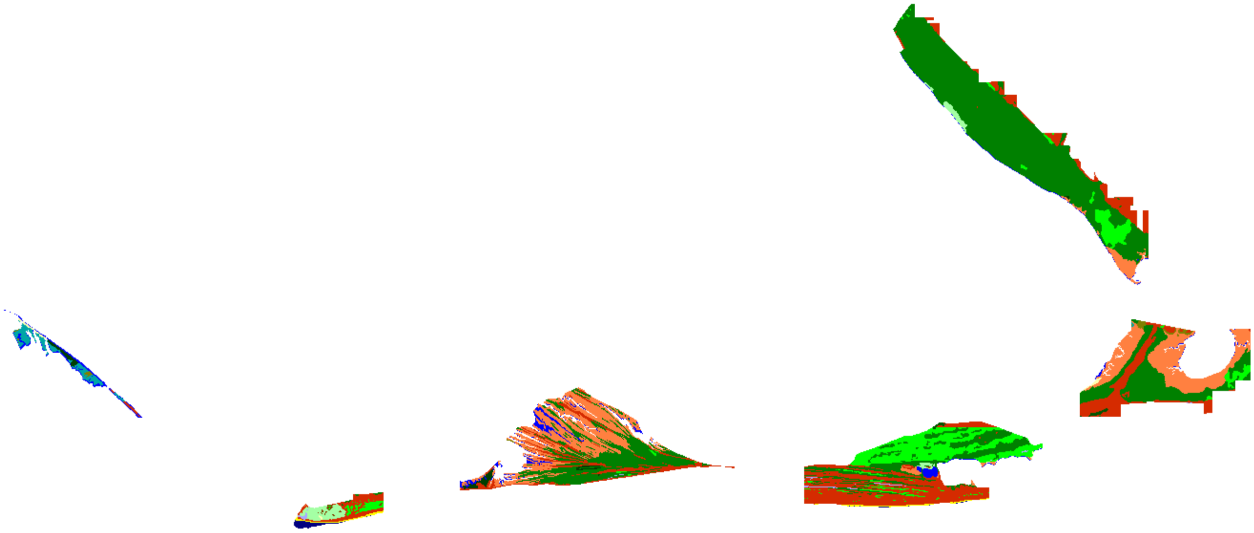


Bon Secour, 2100, 1 Meter Eustatic by 2100

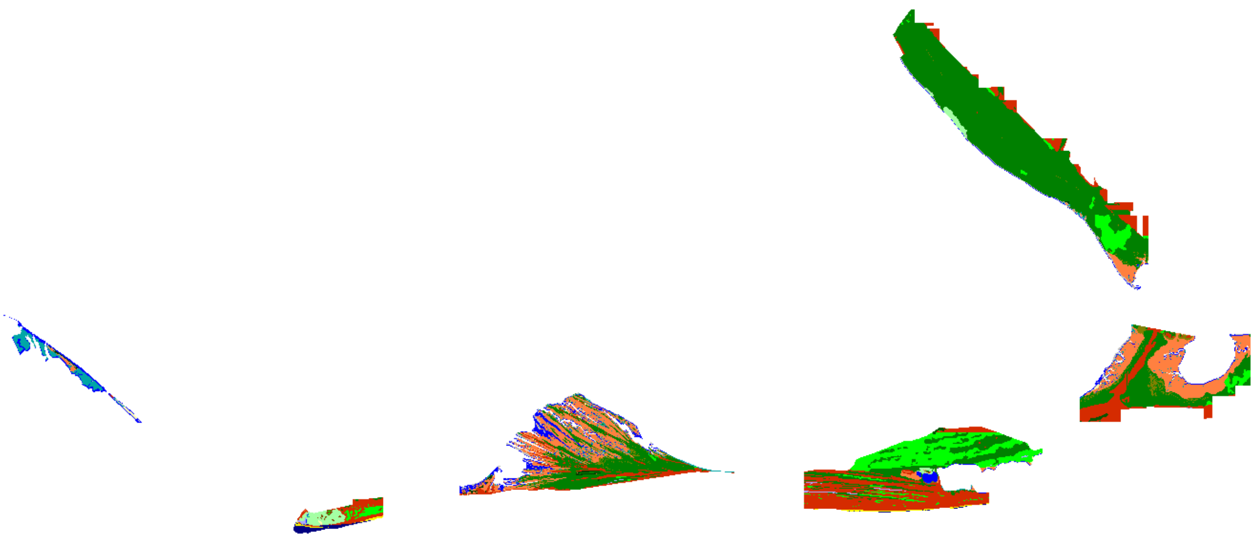
Bon Secour NWR
1.5 Meters Eustatic SLR by 2100

Results in Acres

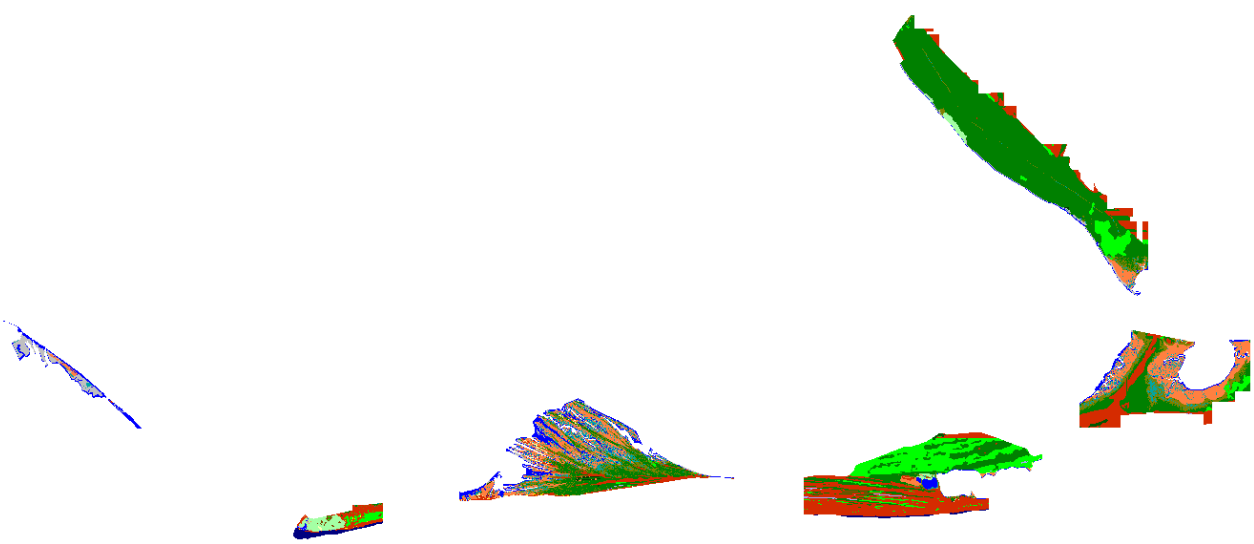
	Initial	2025	2050	2075	2100
Swamp	5510.0	5350.5	4695.8	3641.3	2321.9
Dry Land	2395.0	2201.7	2082.9	1862.1	1562.6
Brackish Marsh	2072.5	1726.6	1387.7	414.8	129.6
Inland Fresh Marsh	1212.3	1215.8	1215.6	1190.7	1139.8
Estuarine Open Water	333.6	474.7	753.4	1290.4	2111.8
Tidal Fresh Marsh	181.5	178.3	174.1	140.4	54.9
Saltmarsh	140.8	340.3	573.4	1676.9	1517.8
Tidal Swamp	87.2	37.9	16.0	4.3	1.7
Ocean Beach	65.8	46.5	8.8	31.1	40.7
Open Ocean	47.6	81.9	135.3	183.3	278.1
Trans. Salt Marsh	46.0	238.2	732.7	1186.8	1531.5
Inland Open Water	38.5	36.9	31.8	29.1	27.8
Estuarine Beach	32.9	38.2	48.8	55.3	44.0
Cypress Swamp	22.5	22.5	22.5	22.5	20.3
Inland Shore	11.3	11.3	11.3	10.5	1.6
Tidal Flat	1.6	197.7	308.8	459.4	1414.9
Total (incl. water)	**12199.0**	**12199.0**	**12199.0**	**12199.0**	**12199.0**



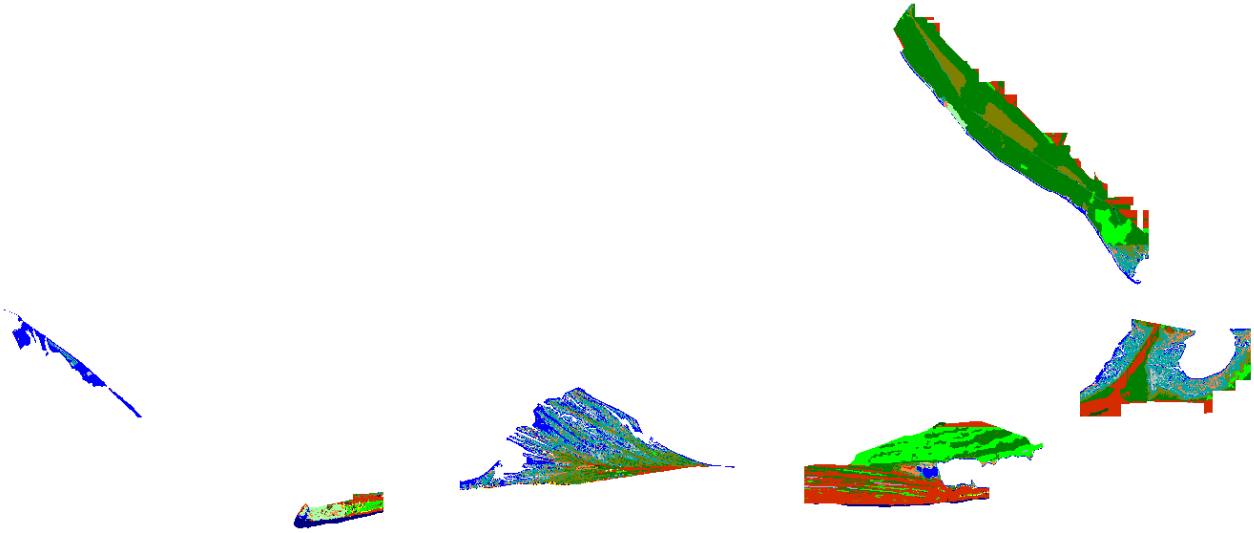
Bon Secour, Initial Condition



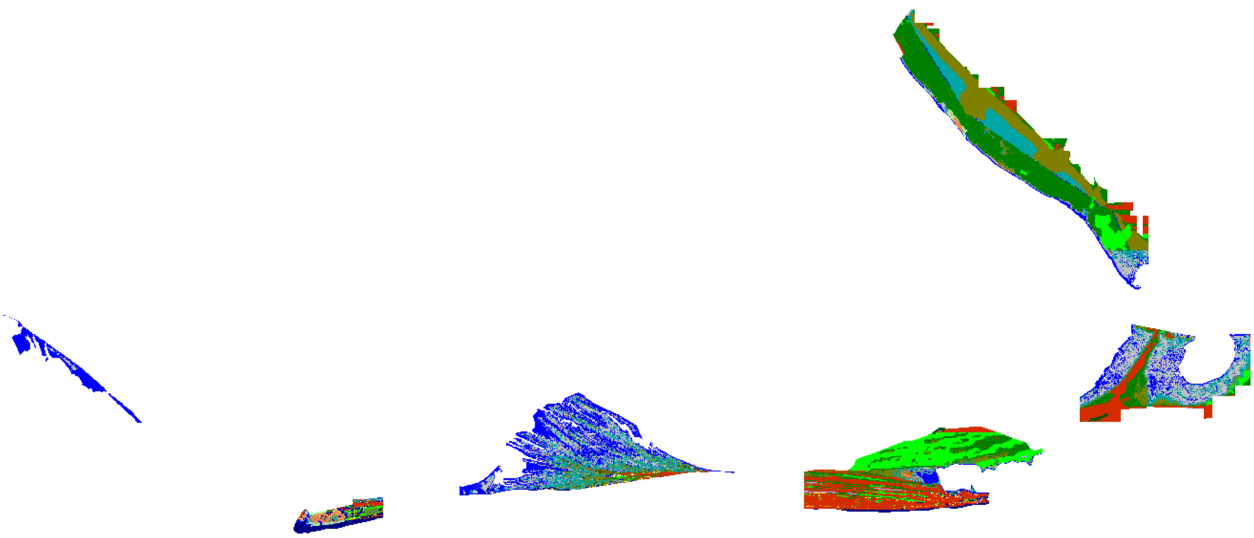
Bon Secour, 2025, 1.5 Meters Eustatic by 2100



Bon Secour, 2050, 1.5 Meters Eustatic by 2100



Bon Secour, 2075, 1.5 Meters Eustatic by 2100

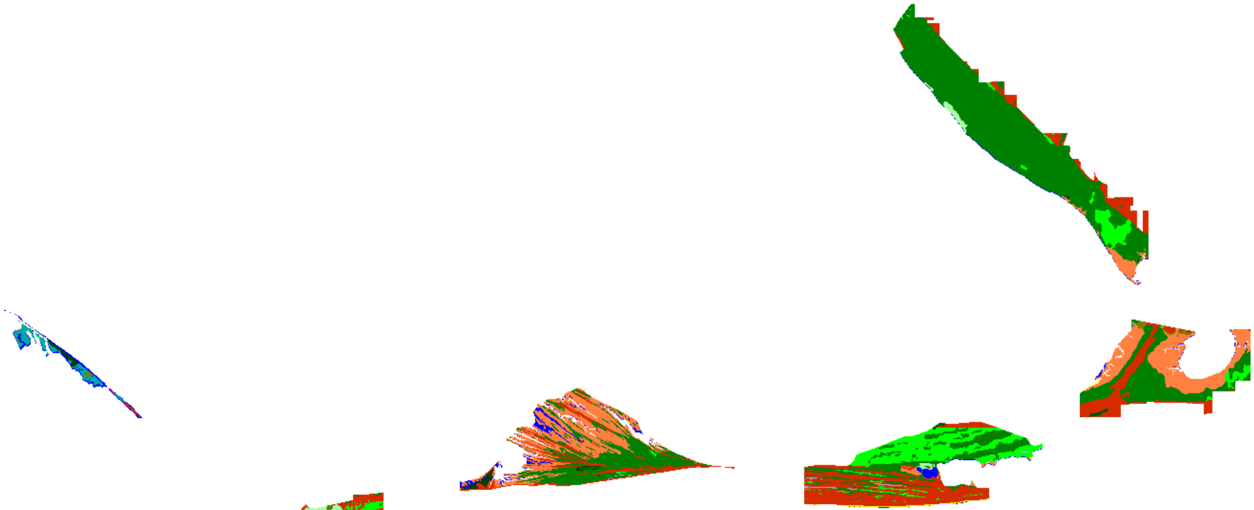


Bon Secour, 2100, 1.5 Meters Eustatic by 2100

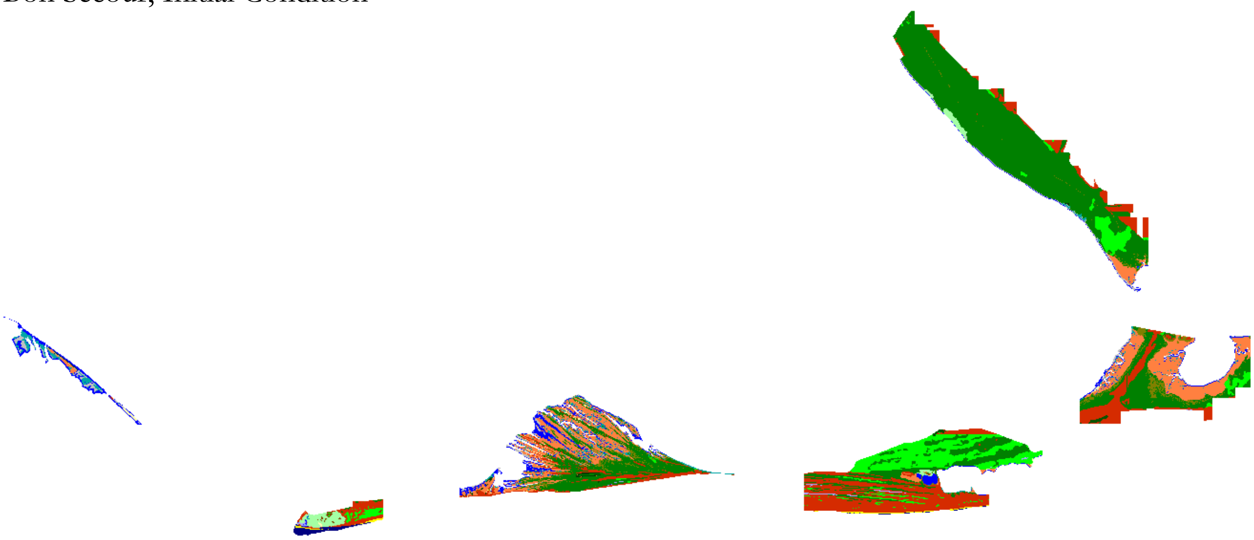
Bon Secour NWR
2 Meters Eustatic SLR by 2100

Results in Acres

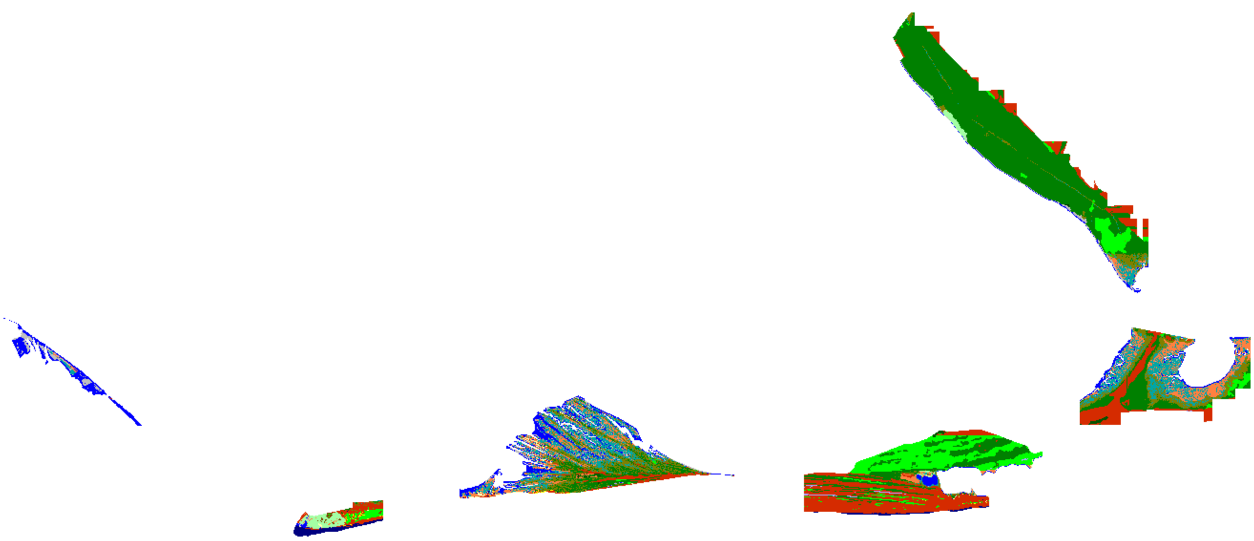
	Initial	2025	2050	2075	2100
Swamp	5510.0	5211.6	4345.4	2612.9	1836.0
Dry Land	2395.0	2184.3	2000.9	1643.0	1240.2
Brackish Marsh	2072.5	1653.6	812.1	160.2	33.2
Inland Fresh Marsh	1212.3	1215.3	1204.7	1138.8	1010.1
Estuarine Open Water	333.6	501.7	899.9	1508.5	2916.8
Tidal Fresh Marsh	181.5	176.9	161.9	53.5	18.7
Saltmarsh	140.8	311.1	1221.0	1679.2	2112.7
Tidal Swamp	87.2	29.7	8.7	2.1	0.2
Ocean Beach	65.8	29.8	20.6	45.9	61.9
Open Ocean	47.6	99.9	147.0	239.5	387.3
Trans. Salt Marsh	46.0	383.6	975.7	1990.9	1076.0
Inland Open Water	38.5	35.4	30.2	28.0	22.5
Estuarine Beach	32.9	47.3	62.3	53.5	59.8
Cypress Swamp	22.5	22.5	22.5	21.4	16.2
Inland Shore	11.3	11.3	11.3	3.8	0.5
Tidal Flat	1.6	284.9	274.6	1017.9	1406.9
Total (incl. water)	**12199.0**	**12199.0**	**12199.0**	**12199.0**	**12199.0**



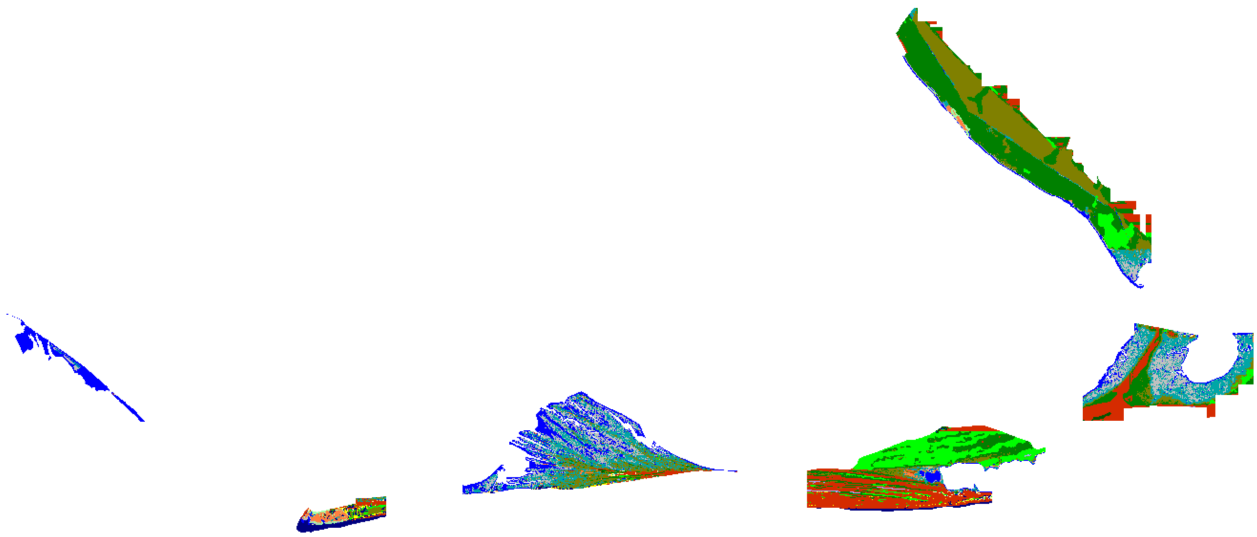
Bon Secour, Initial Condition



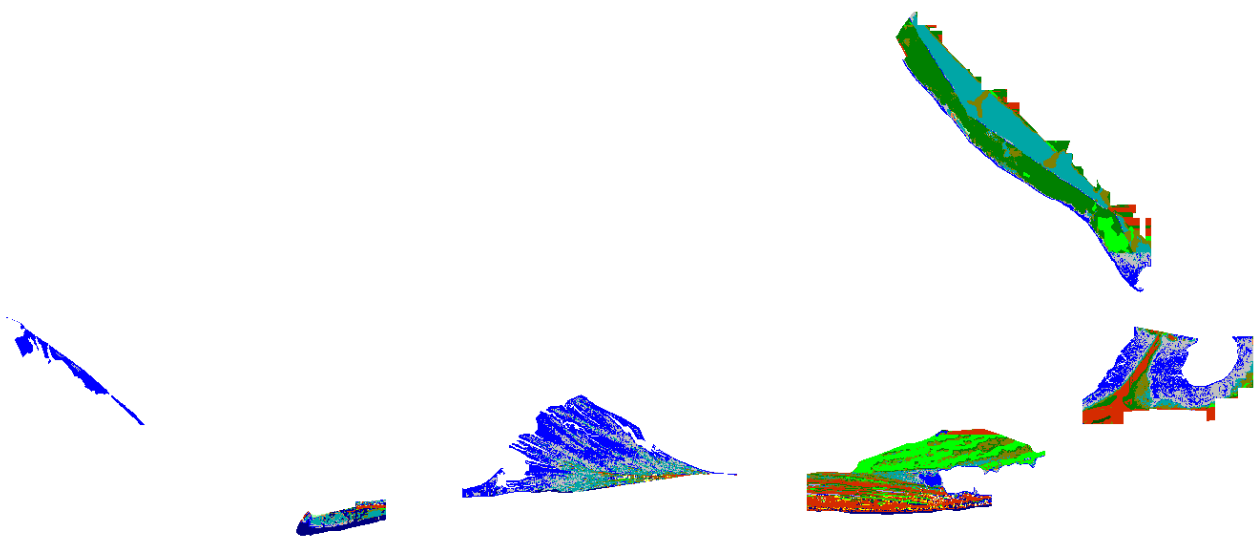
Bon Secour, 2025, 2 Meters Eustatic by 2100



Bon Secour, 2050, 2 Meters Eustatic by 2100



Bon Secour, 2075, 2 Meters Eustatic by 2100



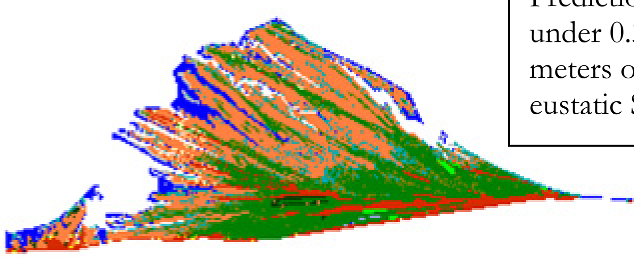
Bon Secour, 2100, 2 Meters Eustatic by 2100

Discussion

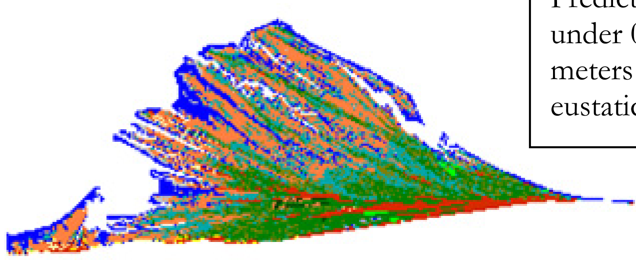
Bon Secour NWR is primarily covered with the best available elevation data (LiDAR). A small portion of the site contains only much lower quality elevation data (based on source data with two meter contours.) The swamp at this site is predicted to be reasonably resilient. It is notable that the locations of swamp losses in high-SLR scenarios appear to be in regions not covered with LiDAR data.

Predictions for dry land loss are moderate at this site, ranging from 14-36% under the scenarios of up to 1.5 meters. Under the 2 meters eustatic SLR scenario, nearly half of dry land is lost, however. Much of the coastal dry land within this refuge is covered by the high-quality LiDAR data.

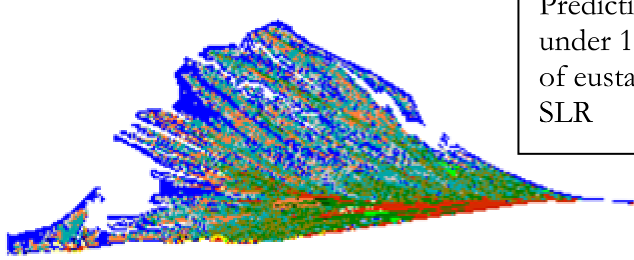
One of the more interesting predictions within this analysis regards the large fringe of brackish marsh that is north of the barrier island at the center of this site. Under scenario A1B-Mean (0.39 meters by 2100) this fringe is largely intact. Under the next-highest scenario (0.69 meters by 2100) this fringe starts to convert to regularly flooded saltmarsh. Under the 1 meter scenario, the results are more severe with open water and tidal flats starting to appear.



Predictions under 0.39 meters of eustatic SLR



Predictions under 0.69 meters of eustatic SLR



Predictions under 1 meter of eustatic SLR

References

Cahoon, D.R., J. W. Day, Jr., and D. J. Reed, 1999. "The influence of surface and shallow subsurface soil processes on wetland elevation: A synthesis." *Current Topics in Wetland Biogeochemistry*, 3, 72-88.

Chen, J. L., Wilson, C. R., Tapley, B. D., 2006 "Satellite Gravity Measurements Confirm Accelerated Melting of Greenland Ice Sheet" *Science* 2006 0: 1129007

Clough, J.S. and R.A. Park, 2007, *Technical Documentation for SLAMM 5.0.1* February 2008, Jonathan S. Clough, Warren Pinnacle Consulting, Inc, Richard A. Park, Eco Modeling. http://warrenpinnacle.com/prof/SLAMM

Craft C, Clough J, Ehman J, Guo H, Joye S, Machmuller M, Park R, and Pennings S. Effects of Accelerated Sea Level Rise on Delivery of Ecosystem Services Provided by Tidal Marshes: A Simulation of the Georgia (USA) Coast. *Frontiers in Ecology and the Environment.* 2009; 7, doi:10.1890/070219

Council for Regulatory Environmental Modeling, (CREM) 2008. *Draft guidance on the development, evaluation, and application of regulatory environmental* models P Pascual, N Stiber, E Sunderland - Washington DC: Draft, August 2008

Galbraith, H., R. Jones, R.A. Park, J.S. Clough, S. Herrod-Julius, B. Harrington, and G. Page. 2002. Global Climate Change and Sea Level Rise: Potential Losses of Intertidal Habitat for Shorebirds. *Waterbirds* 25:173-183.

Glick, Clough, et al. *Sea-level Rise and Coastal Habitats in the Pacific Northwest An Analysis for Puget Sound, Southwestern Washington, and Northwestern Oregon* July 2007 http://www.nwf.org/sealevelrise/pdfs/PacificNWSeaLevelRise.pdf

IPCC, 2001: *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [Houghton, J.T.,Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K.Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881pp.

Lee, J.K., R.A. Park, and P.W. Mausel. 1992. Application of Geoprocessing and Simulation Modeling to Estimate Impacts of Sea Level Rise on the Northeast Coast of Florida. *Photogrammetric Engineering and Remote Sensing* 58:11:1579-1586.

Meehl GA, Stocker TF, Collins WD, Friedlingstein P, Gaye AT, Gregory JM, Kitoh A, Knutti R, Murphy JM, Noda A, Raper SCB, Watterson IG, Weaver AJ and Zhao ZC. 2007. Global climate projections. Pp. 747-845. In: Solomon S, Qin, D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor, M and Miller HL, (eds.) *Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK: Cambridge University Press.

Monaghan, A. J. *et al,* 2006 "Insignificant Change in Antarctic Snowfall Since the International Geophysical Year" *Science* 2006 313: 827-831.

Moorhead, KK and Brinson MM. 1995. Response of wetlands to rising sea level in the lower coastal plain of North Carolina. *Ecological Applications* 5: 261-271.

National Wildlife Fed 'n et al., *An Unfavorable Tide: Global Warming, Coastal Habitats and Sportfishing in Florida* 4, 6 (2006). http://www.targetglobalwarming.org/files/AnUnfavorableTideReport.pdf

Park, R.A., J.K. Lee, and D. Canning. 1993. Potential Effects of Sea Level Rise on Puget Sound Wetlands. *Geocarto International* 8(4):99-110.

Park, R.A., M.S. Trehan, P.W. Mausel, and R.C. Howe. 1989a. The Effects of Sea Level Rise on U.S. Coastal Wetlands. In *The Potential Effects of Global Climate Change on the United States: Appendix B - Sea Level Rise,* edited by J.B. Smith and D.A. Tirpak, 1-1 to 1-55. EPA-230-05-89-052. Washington, D.C.: U.S. Environmental Protection Agency.

Pfeffer, Harper, O'Neel, 2008. Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise. *Science*, Vol. 321, No. 5894. (5 September 2008), pp. 1340-134

Rahmstorf, Stefan 2007, "A Semi-Empirical Approach to Projecting Future Sea-Level Rise," *Science* 2007 315: 368-370.

Rodriguez, E., C.S. Morris, J.E. Belz, E.C. Chapin, J.M. Martin, W. Daffer, S. Hensley, 2005, *An assessment of the SRTM topographic products*, Technical Report JPL D-31639, Jet Propulsion Laboratory, Pasadena, California, 143 pp.

Reed, D.J., D.A. Bishara, D.R. Cahoon, J. Donnelly, M. Kearney, A.S. Kolker, L.L. Leonard, R.A. Orson, and J.C. Stevenson, 2008: "Site-Specific Scenarios for Wetlands Accretion in the Mid-Atlantic Region. Section 2.1" in *Background Documents Supporting Climate Change Science Program Synthesis and Assessment Product 4.1: Coastal Elevations and Sensitivity to Sea Level Rise*, J.G. Titus and E.M. Strange (eds.), EPA430R07004, Washington, DC: U.S. EPA. http://www.epa.gov/climatechange/effects/downloads/section2_1.pdf

Stevenson and Kearney, 2008, "Impacts of Global Climate Change and Sea-Level Rise on Tidal Wetlands" Pending chapter of manuscript by University of California Press.

Titus, J.G., R.A. Park, S.P. Leatherman, J.R. Weggel, M.S. Greene, P.W. Mausel, M.S. Trehan, S. Brown, C. Grant, and G.W. Yohe. 1991. Greenhouse Effect and Sea Level Rise: Loss of Land and the Cost of Holding Back the Sea. *Coastal Management* 19:2:171-204.

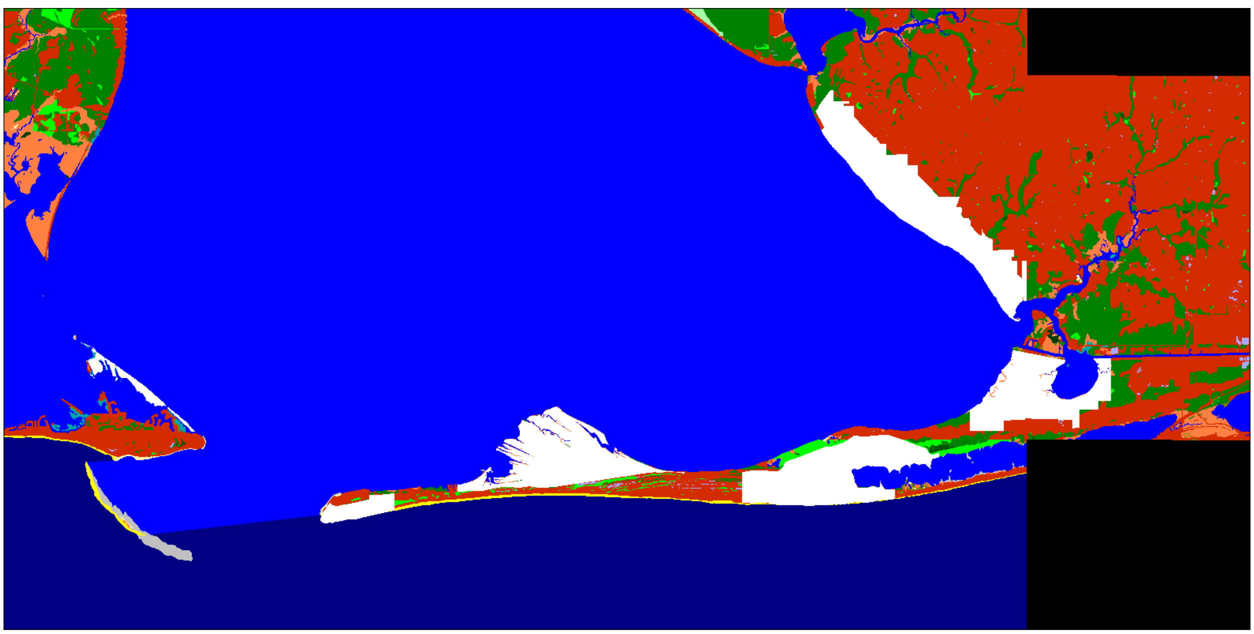
US Climate Change Science Program, 2008, Abrupt *Climate Change, Final Report, Synthesis and Assessment Product 3.4*, U.S. Climate Change Science Program And the Subcommittee on Global Change Research, Lead Agency U. S. Geological Survey, Contributing Agencies National Oceanic and Atmospheric Administration, National Science Foundation.

Appendix A: Contextual Results

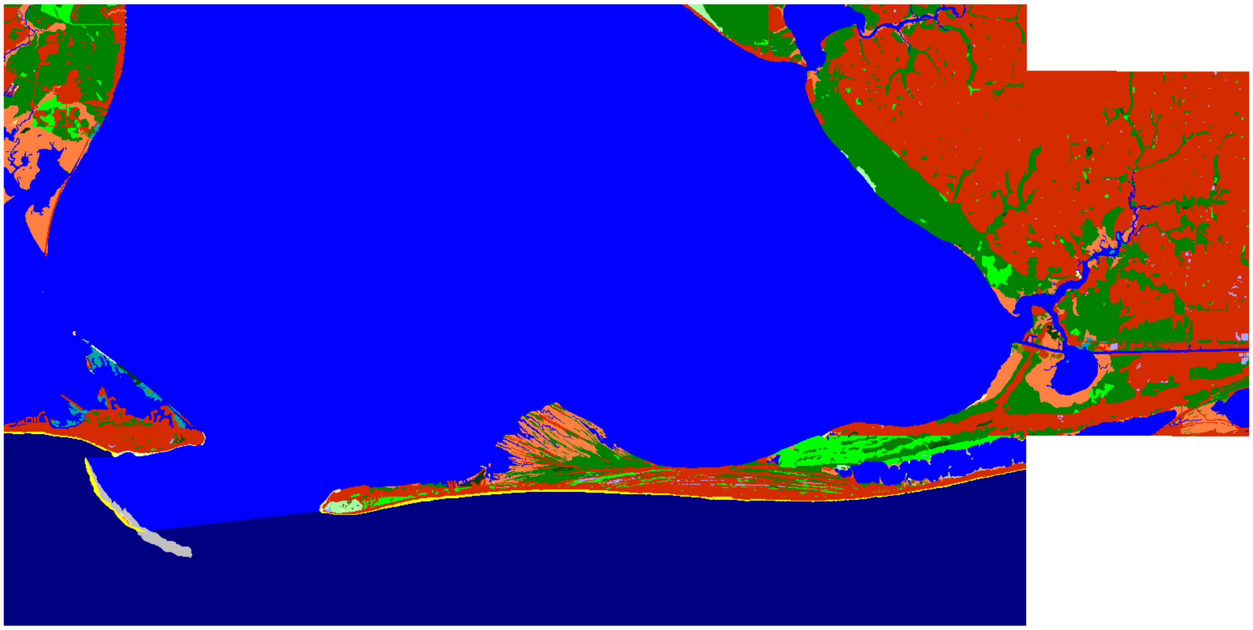
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated dry lands will convert to marshes or ocean beach depending on their proximity to open ocean.

For this reason, an area larger than the boundaries of the USFWS refuge was modeled. These results maps are presented here with the following caveats:

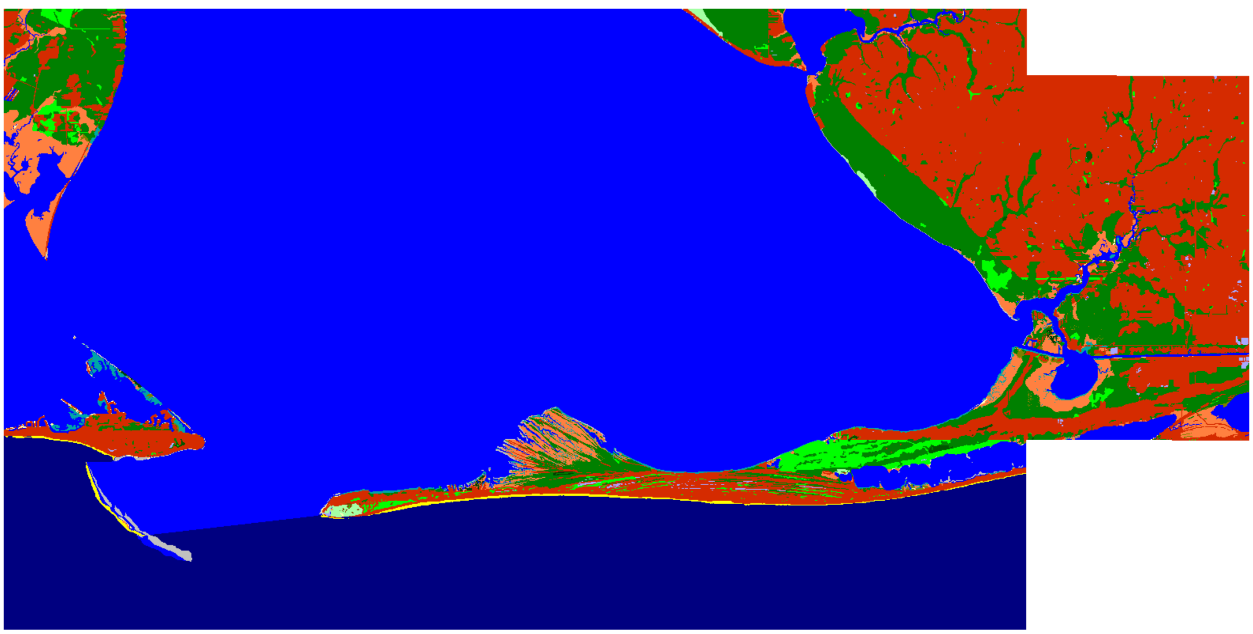
- Results were closely examined (quality assurance) within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort was made to assess the probable location and effects of dikes for USFWS refuges, but this effort was not made for surrounding areas.



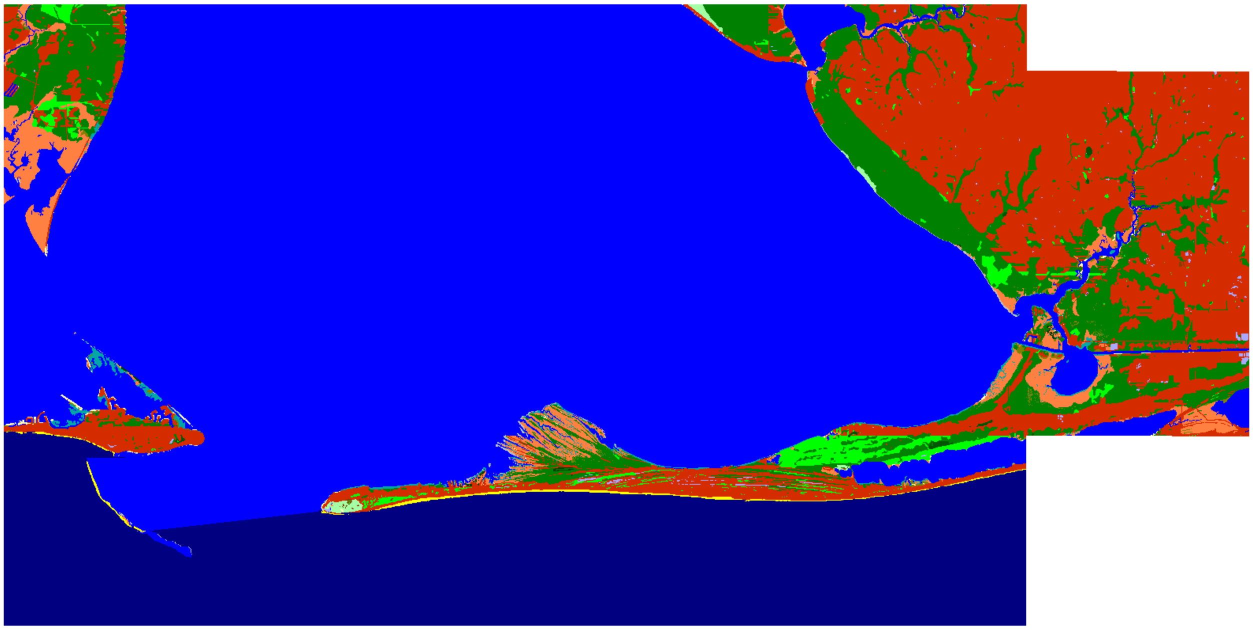
Location of Bon Secour National Wildlife Refuge within Alabama Contextual Simulation

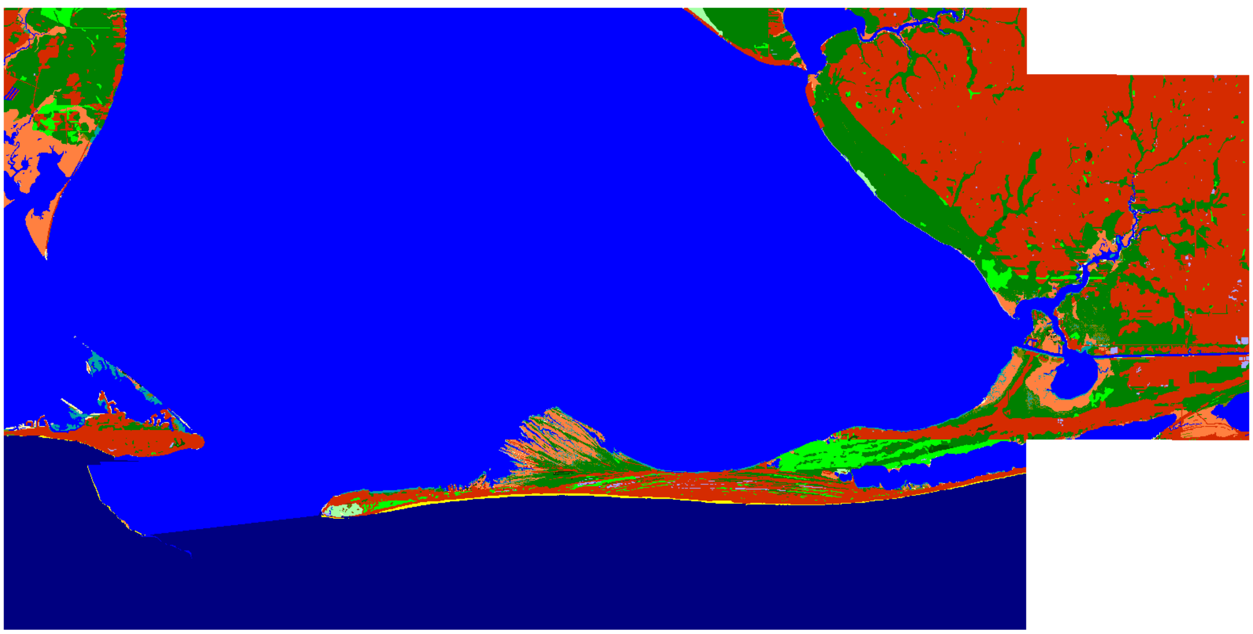


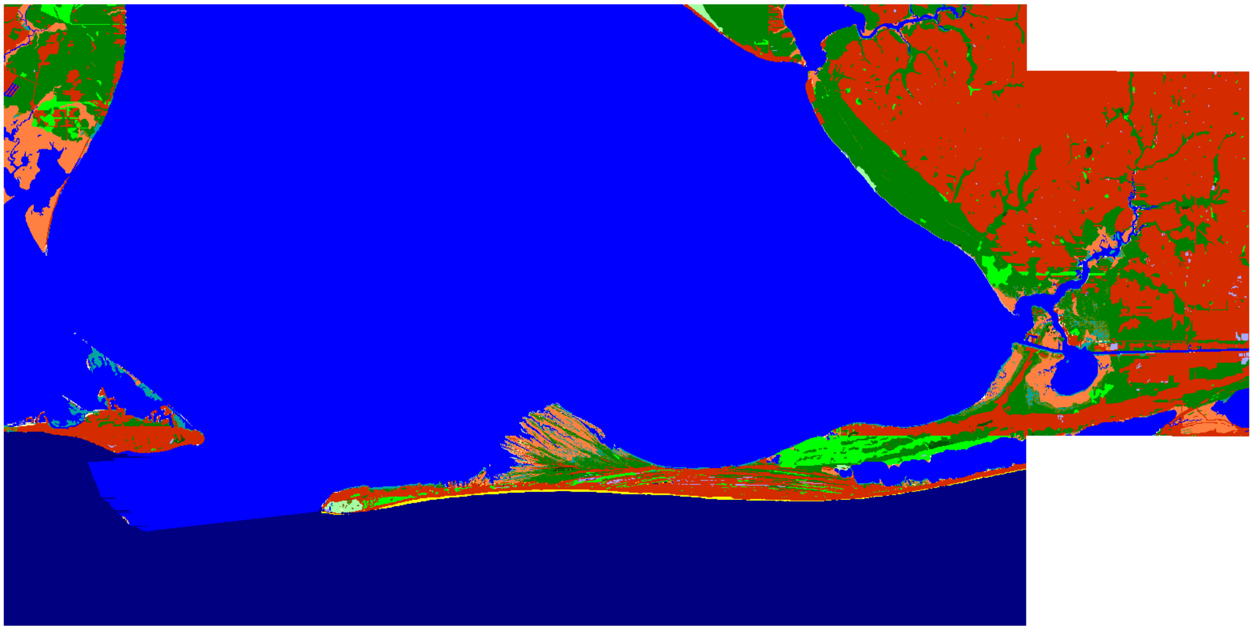
Alabama Initial Condition



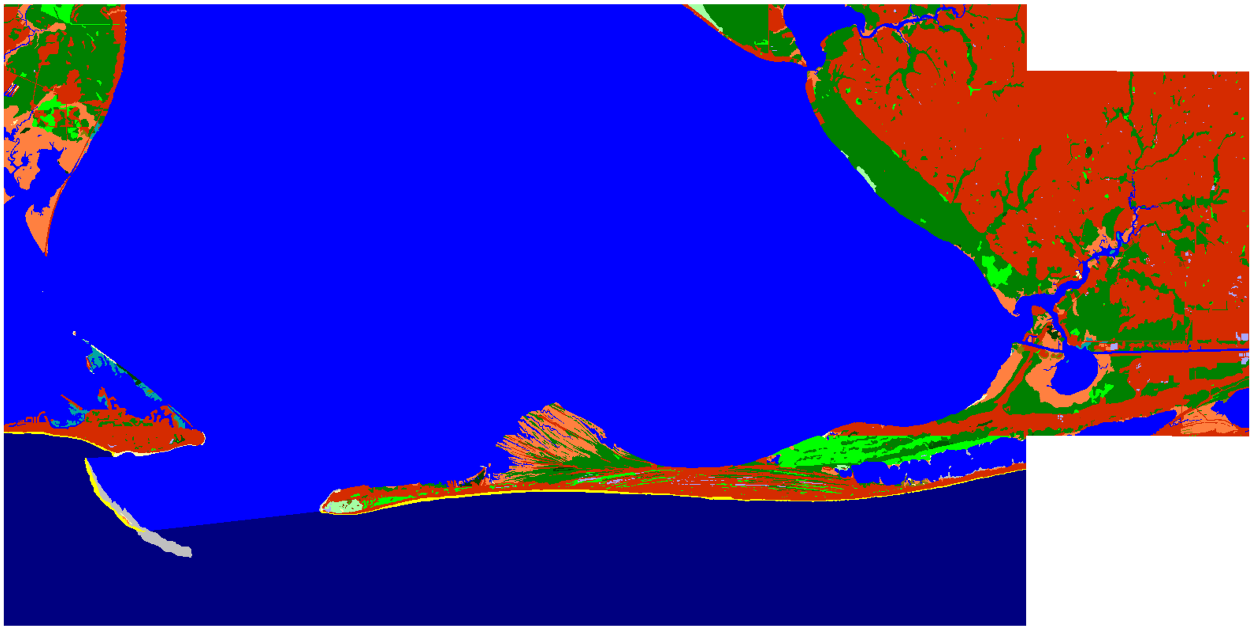
Alabama 2025, Scenario A1B Mean


Alabama 2050, Scenario A1B Mean

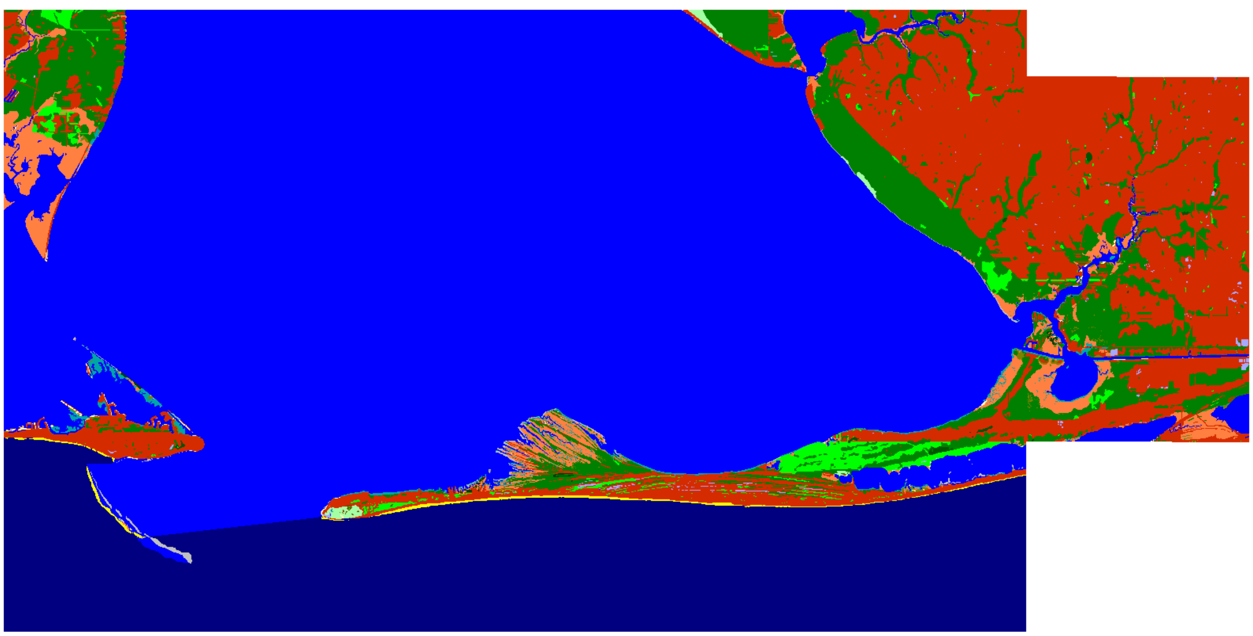

Alabama 2075, Scenario A1B Mean



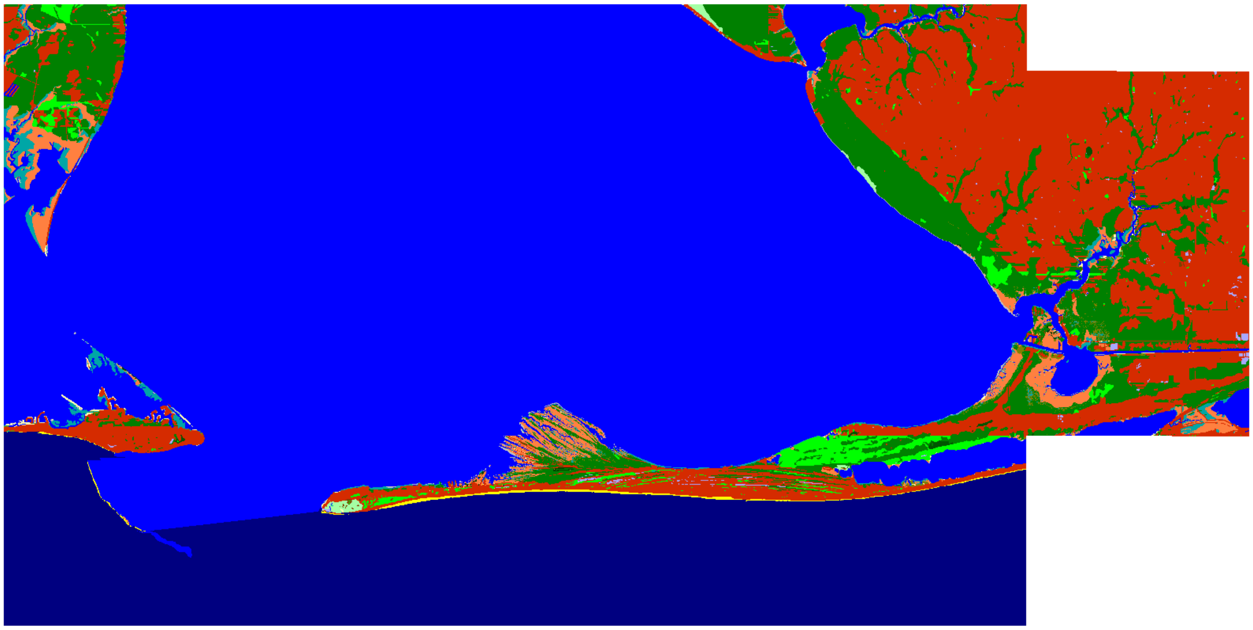
Alabama 2100, Scenario A1B Mean



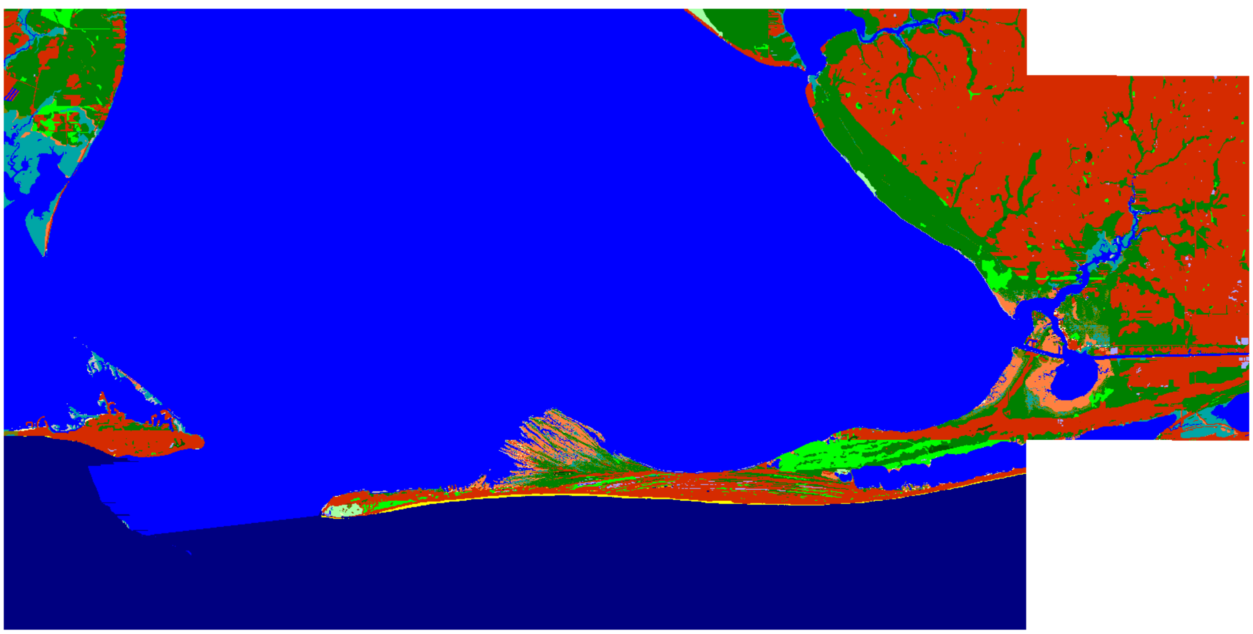
Alabama Initial Condition



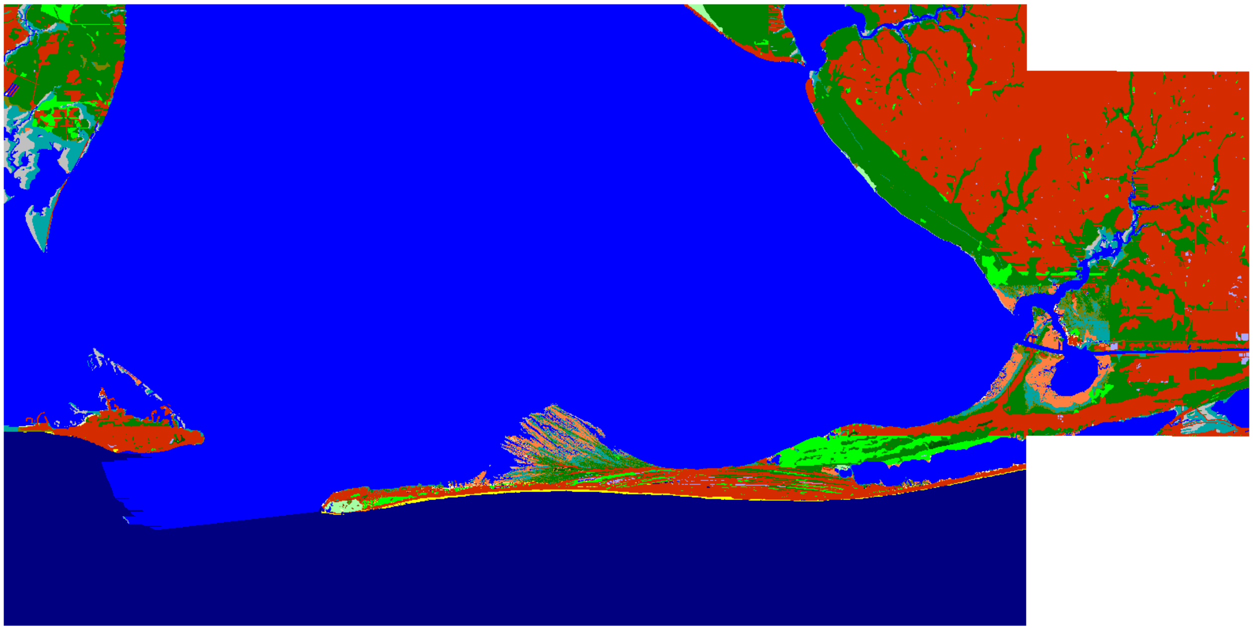
Alabama 2025, Scenario A1B Maximum

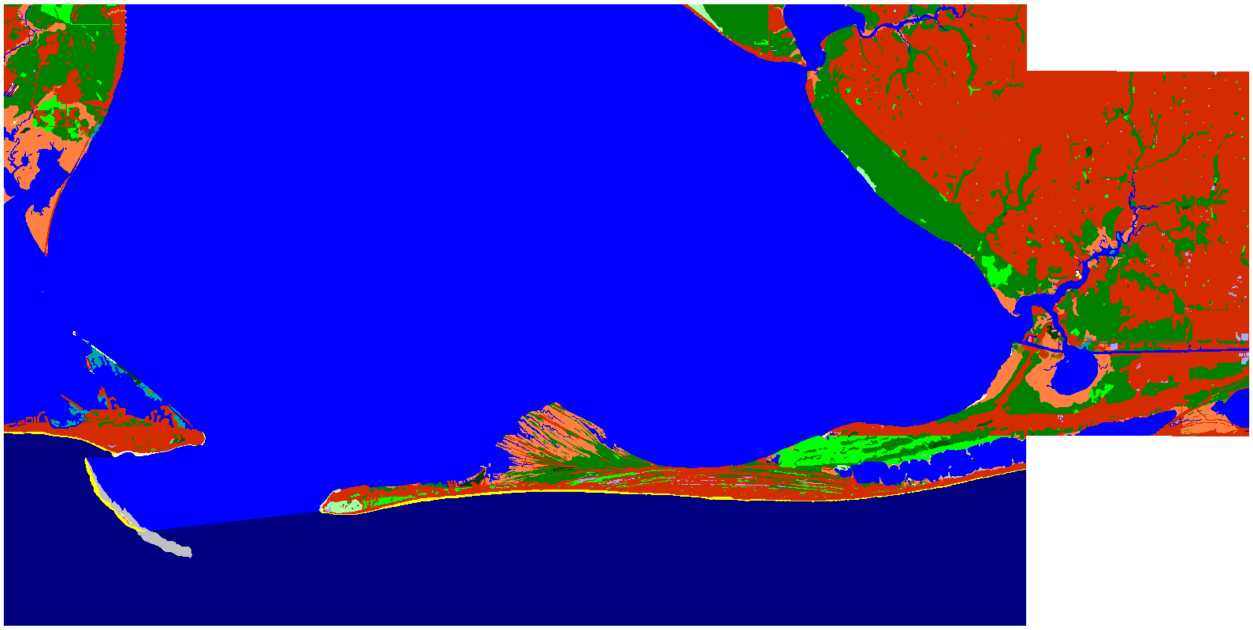


Alabama 2050, Scenario A1B Maximum

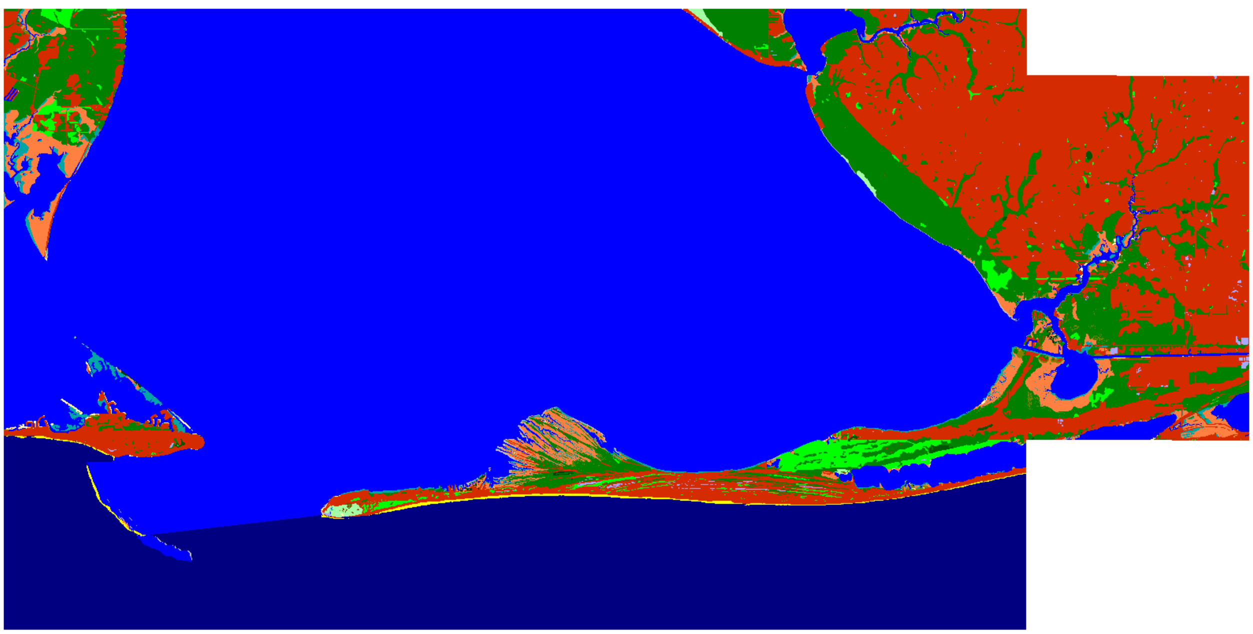


Alabama 2075, Scenario A1B Maximum

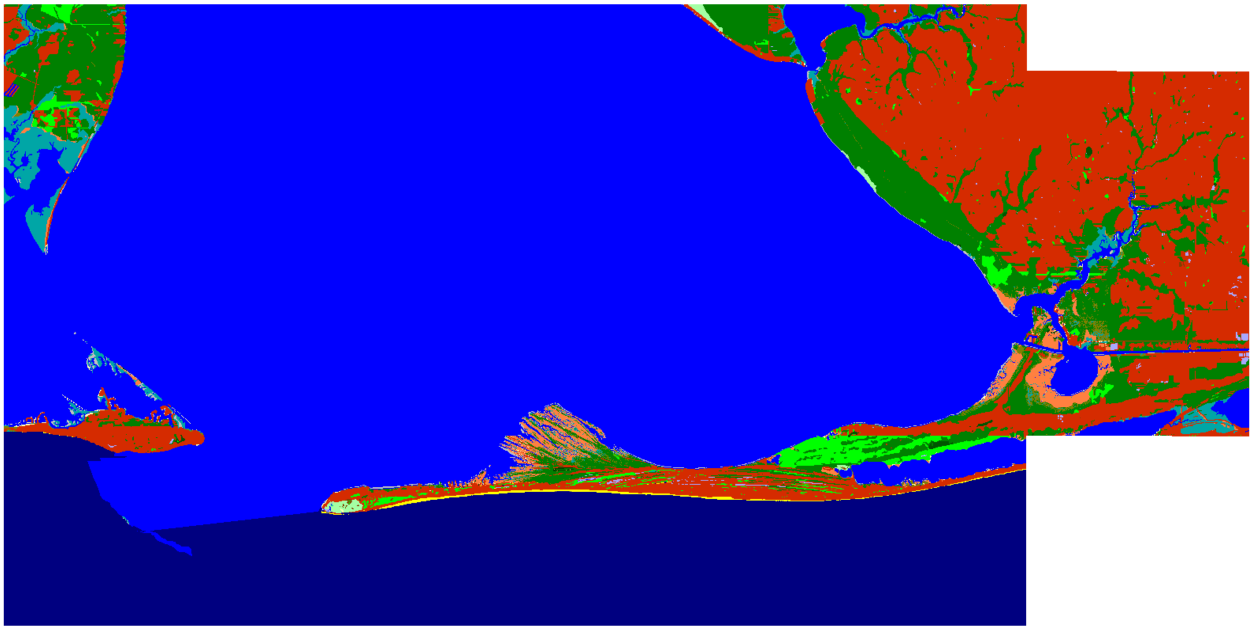

Alabama 2100, Scenario A1B Maximum



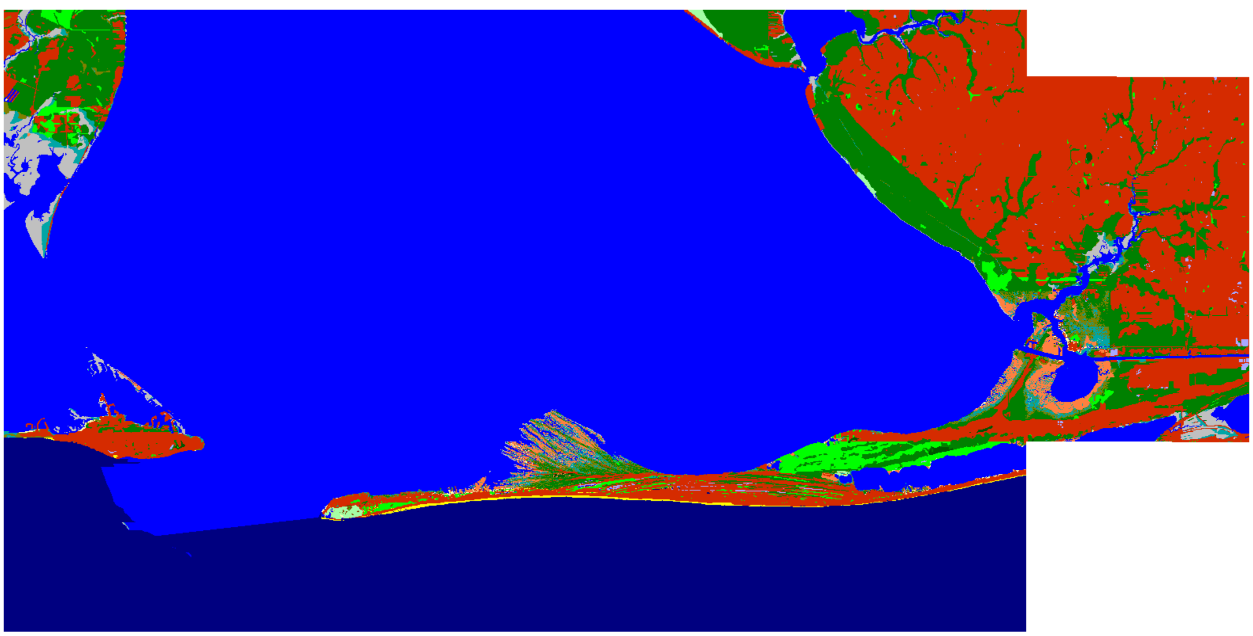
Alabama Initial Condition



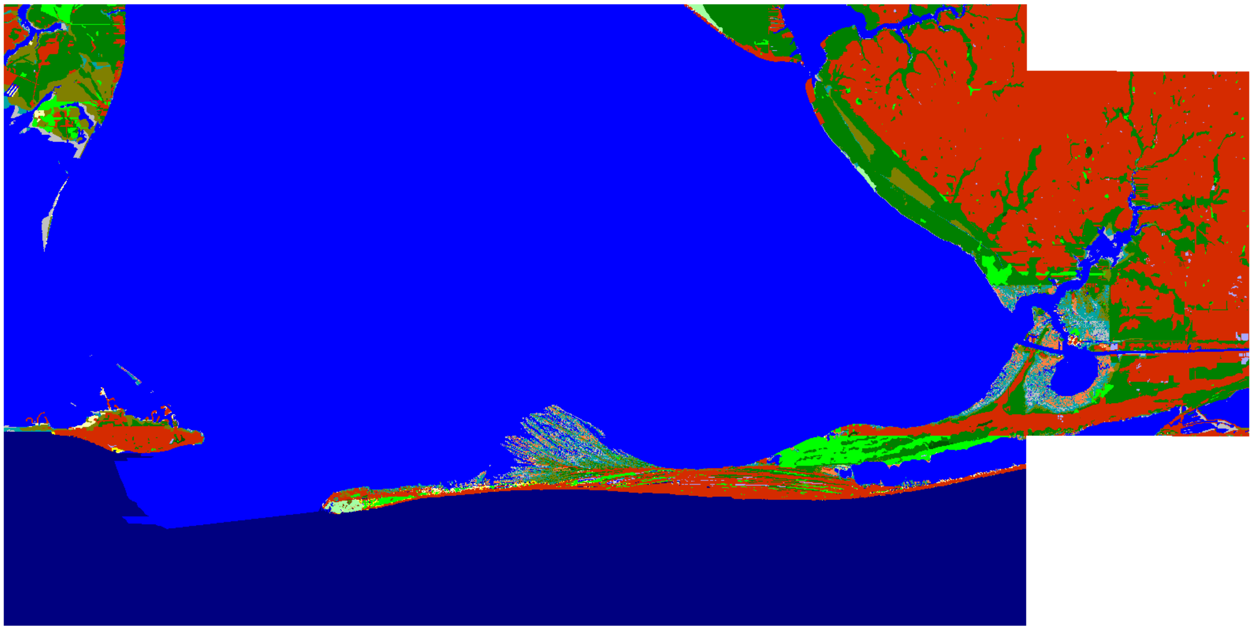
Alabama 2025, 1 Meter Eustatic by 2100



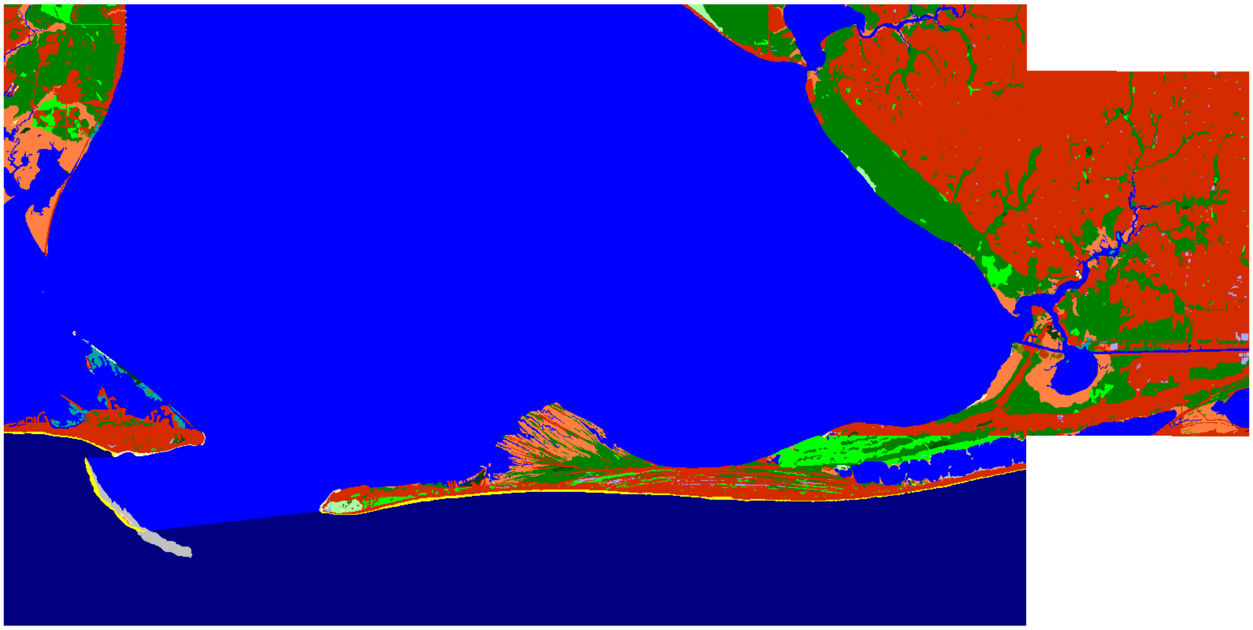
Alabama 2050, 1 Meter Eustatic by 2100



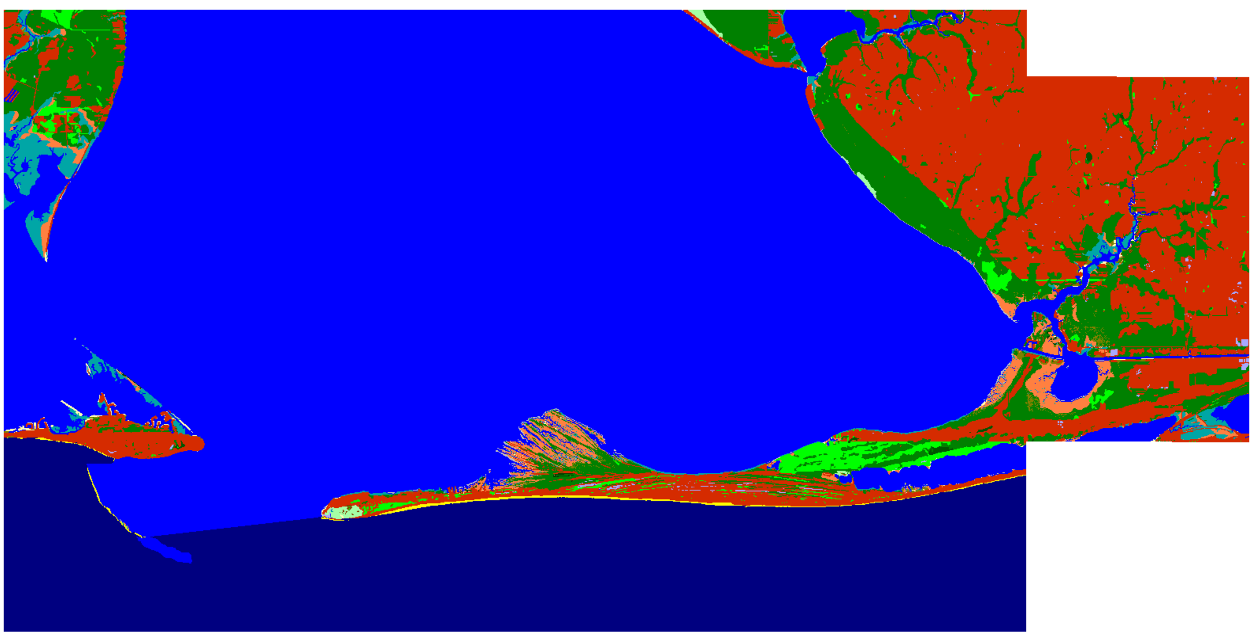
Alabama 2075, 1 Meter Eustatic by 2100



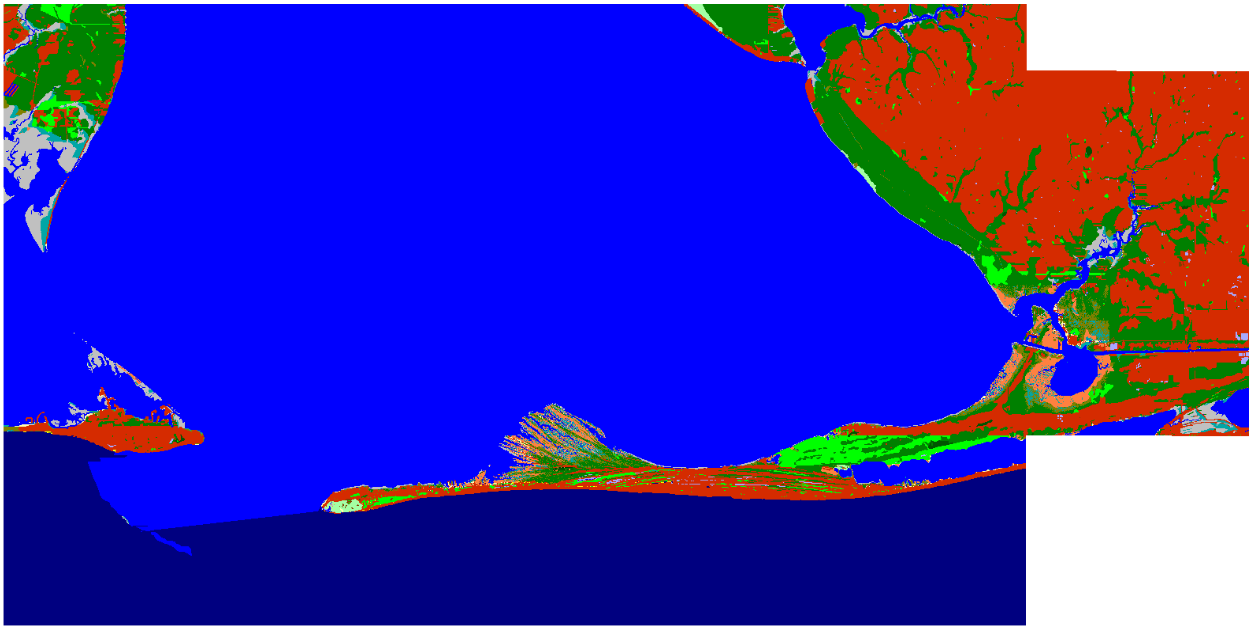
Alabama 2100, 1 Meter Eustatic by 2100



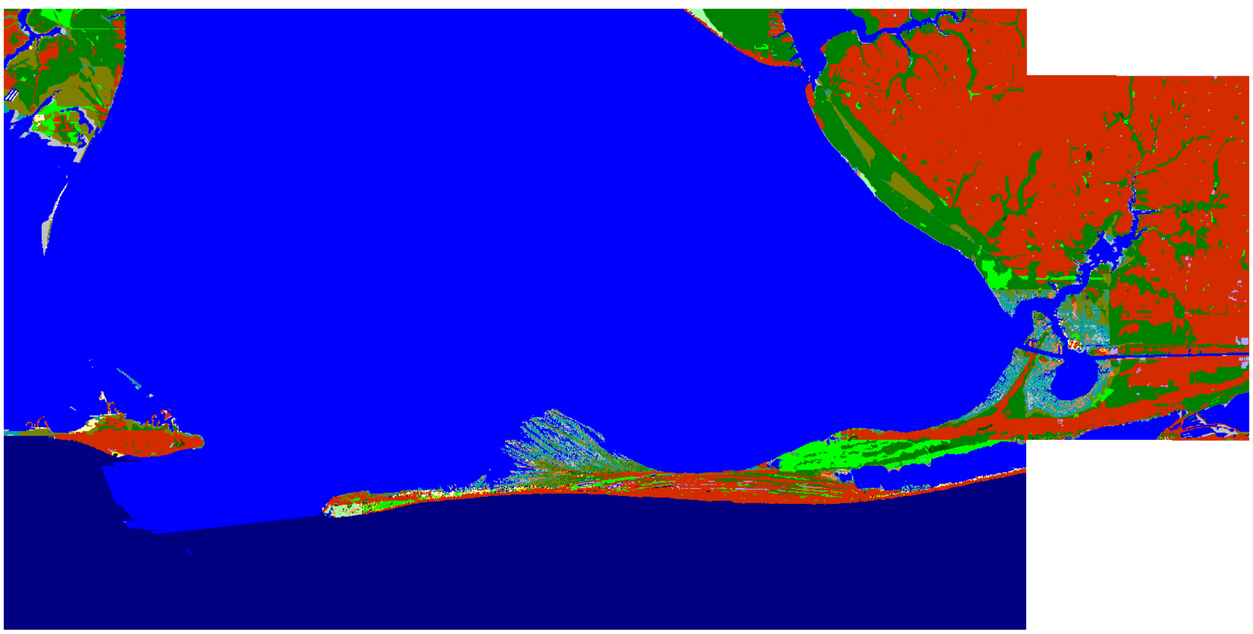
Alabama Initial Condition



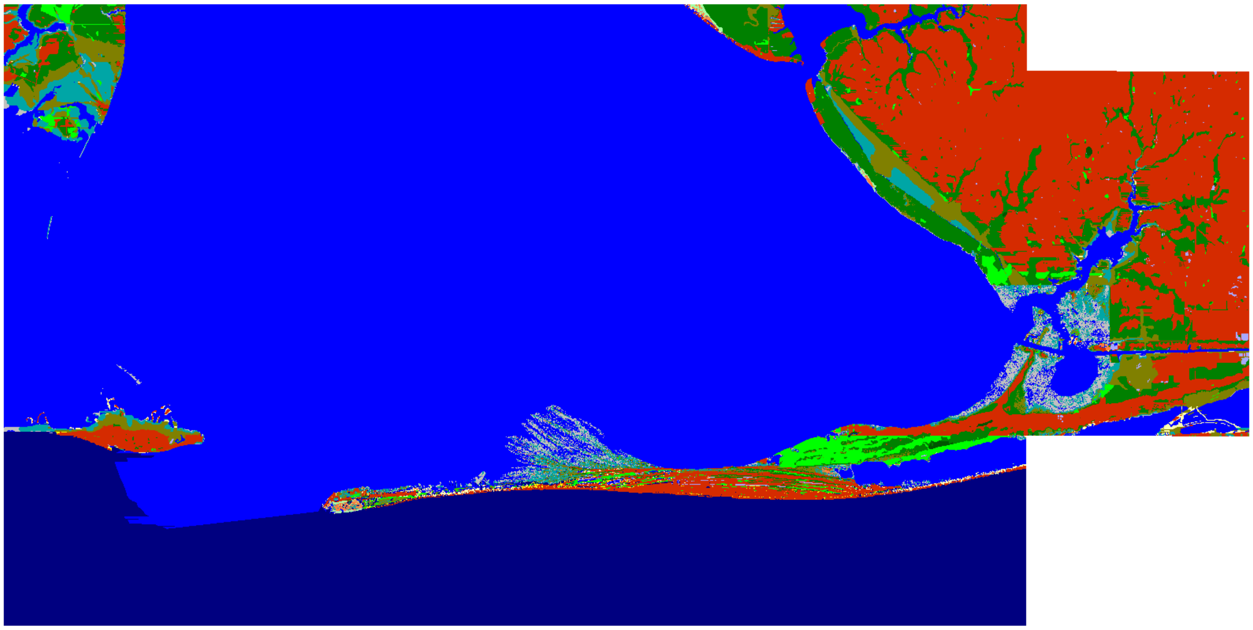
Alabama 2025, 1.5 Meters Eustatic by 2100



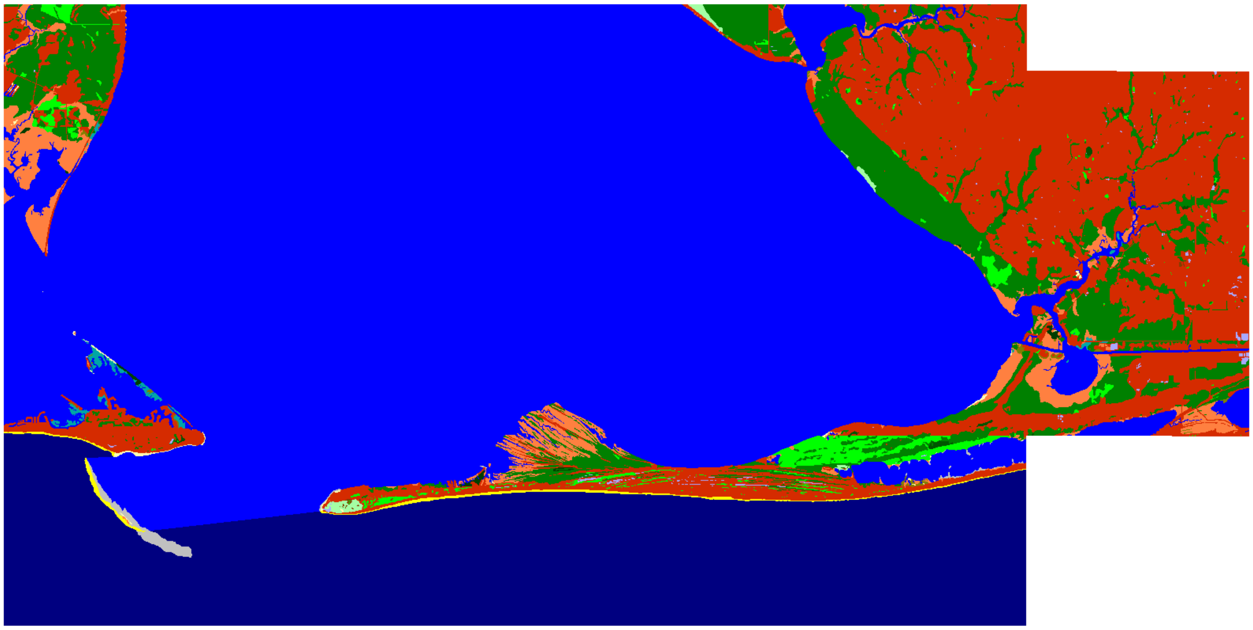
Alabama 2050, 1.5 Meters Eustatic by 2100



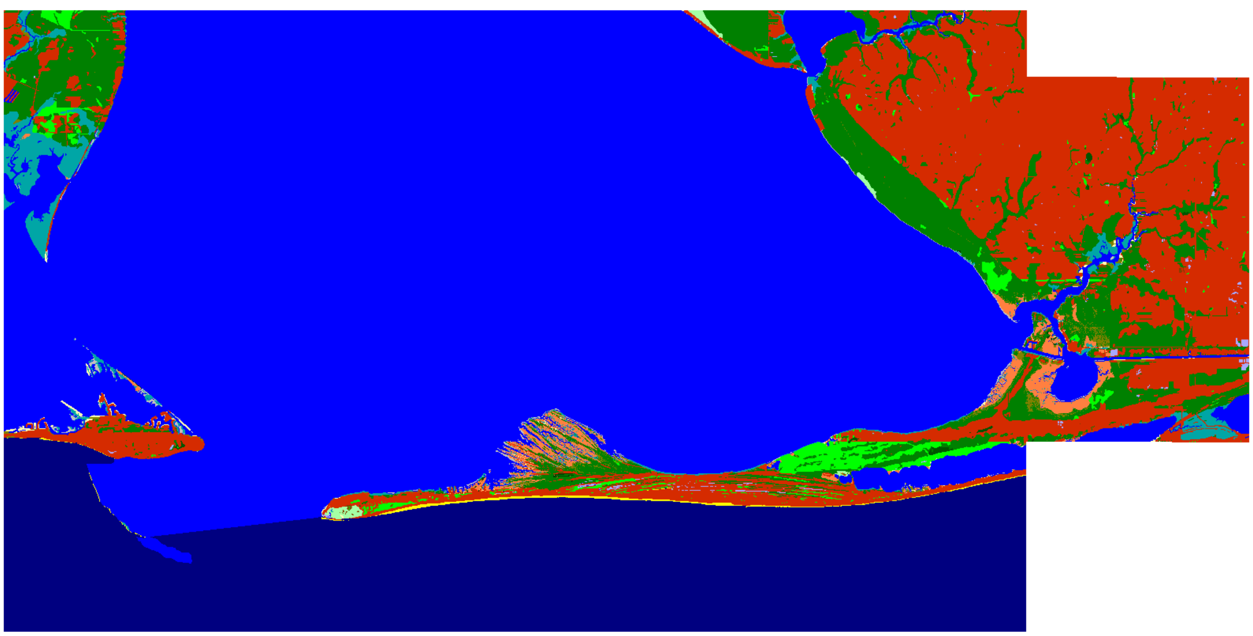
Alabama 2075, 1.5 Meters Eustatic by 2100



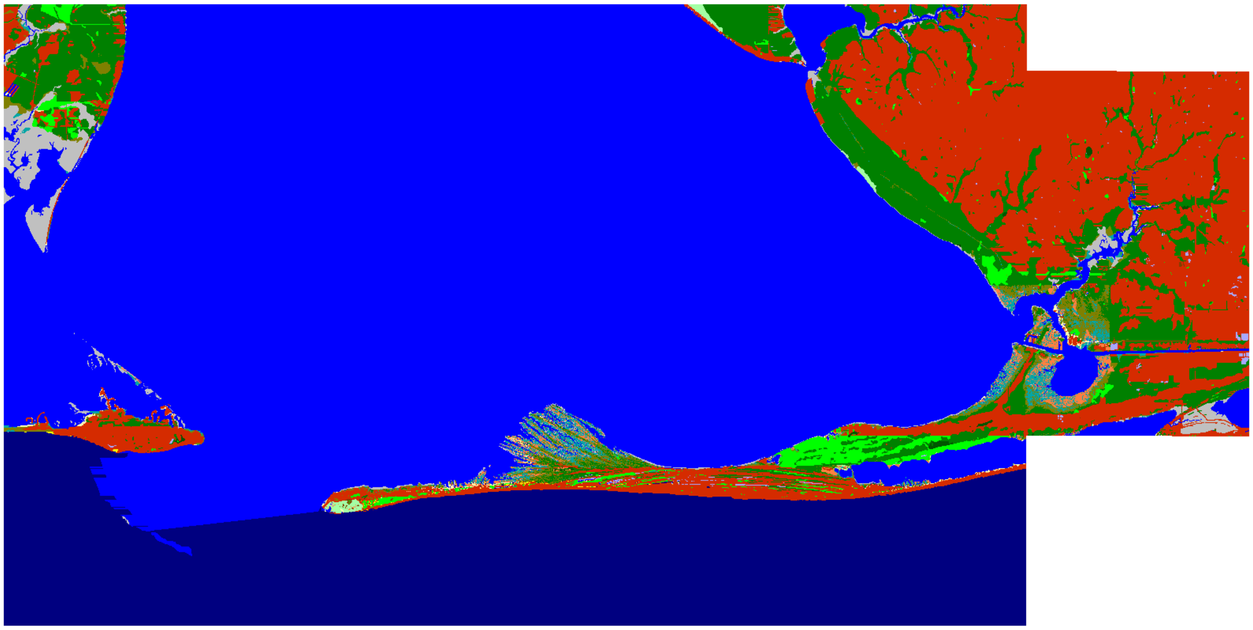
Alabama 2100, 1.5 Meters Eustatic by 2100



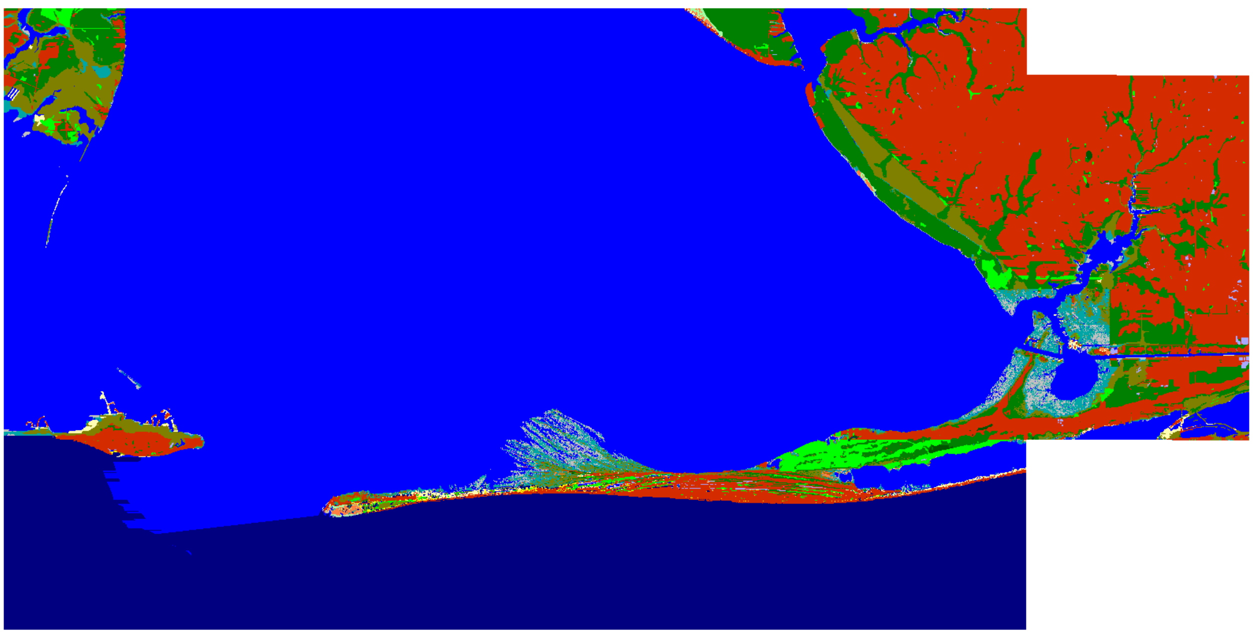
Alabama Initial Condition



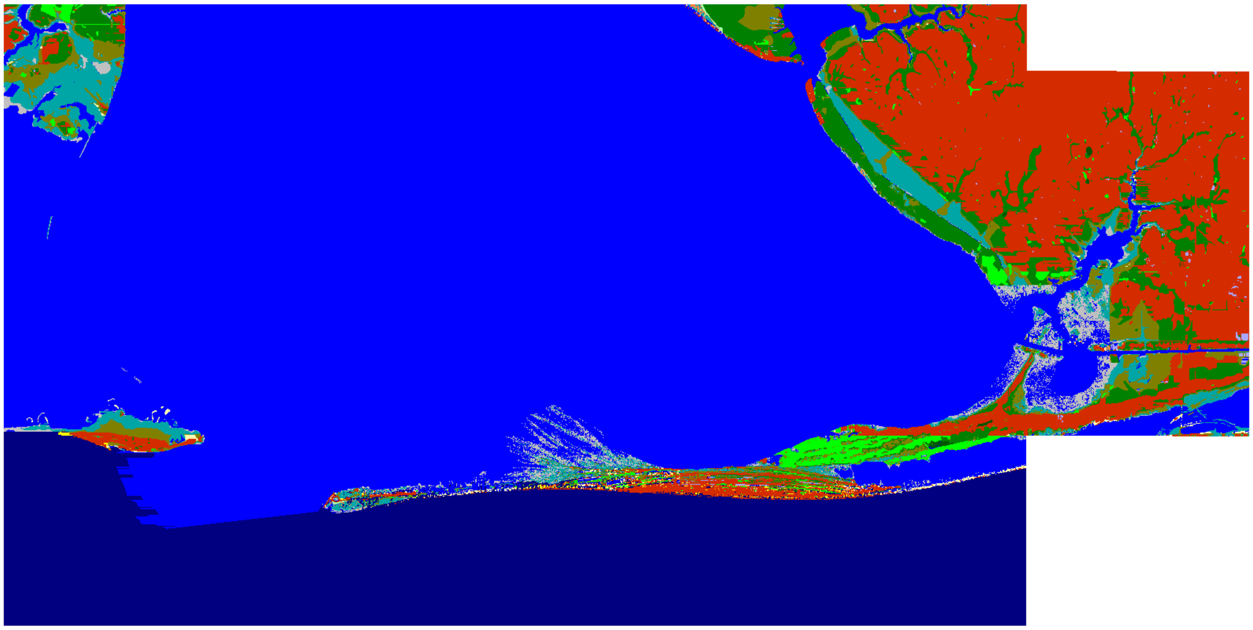
Alabama 2025, 2 Meters Eustatic by 2100



Alabama 2050, 2 Meters Eustatic by 2100



Alabama 2075, 2 Meters Eustatic by 2100



Alabama 2100, 2 Meters Eustatic by 2100